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## ON THE THERMAL DEVELOPMENT OF THE SPARK SPECTRUM OF CARBON.[1]

By HENRY CREW and JOHN C. BAKER.

DURING the course of some experiments which Professor Basquin was making on the production of arc and spark spectra from the same electrodes, it was observed by one of us, standing at the eyepiece of his spectroscope, that the lines of the spark spectrum made their appearance gradually, and not suddenly, beginning at the instant at which the direct current feeding the arc was cut off and the high-voltage current producing the spark was switched on.

It was evident at once that the appearance of these lines in deliberate succession was due, primarily at least, to the gradual cooling of the electrodes and of the region between them. But we were uncertain whether, after all, the effect was not merely a physiological one, the lines first observed being the stronger lines, and those observed later being the weaker lines. We accordingly set about making a series of photographs which

[1] The expenses of this experiment were met by the consideration of the committee in charge of the Rumford Fund.

should show the spark spectrum at each successive instant, beginning at the time at which the arc current is interrupted.

At first our attempt was to employ metallic spark-electrodes; and in order to retard the development of the spark as much as possible, the carbon electrodes were enclosed between two saucer-shaped clay scorifiers as shown in Fig. 1. The terminals of the spark circuit were introduced into this cell at right angles to those of the arc. Various other forms of cells, hollowed limes from the stereopticon, clay pipes, fire brick, etc., were tried. But in each case, as soon as the region inside got hot enough to affect the character of the spark and render it quiet, we found (as indeed ought to have been anticipated) that the walls of the vessel became conducting.

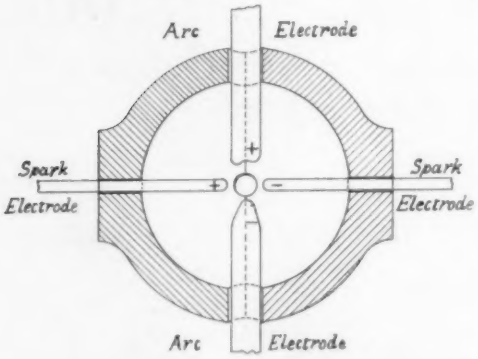



FIG. 1.

We tried next to get a gradual variation of temperature by moving the spark gap slowly from the center to the edge of an ordinary carbon arc, knowing that, at the center of the arc, the spark was quiet and non-luminous while just outside the arc it became noisy and brilliant. But in carrying the spark electrodes from one of these positions to the other, we encountered a peculiar discontinuity, *i. e.*, a position at which the spark *instantly* changed character.

When the spark was passed through the "horsetail" above the horizontal arc at a distance of from ½ to 2 centimeters from the arc, the quiet discharge mentioned above was still obtained and a spectrum of feeble intensity could be observed. When, however, the terminals were removed slightly further above the arc, a point was reached at which the discharge instantly assumed the ragged character of the ordinary cold

spark; and when the spark was then moved back toward the arc it did not resume its quiet character, but blew the "horsetail" away, and in most cases put out the arc. It did not seem possible to obtain any intermediate stages. The instability was very marked. The spark was liable at any time to break down into the ragged character and when it had once done so it retained that character until the circuit was broken.

APPARATUS AND METHOD.

Accordingly we had recourse to soft-cored carbons worked in air, using the same electrodes for both arc and spark; in other words, we used the hot region between the poles of an ordinary carbon arc as the heated medium in which to study the slowly developing spark.

The next step consisted in isolating the particular phase of the development which we wished to examine.

This was accomplished by means of a device (designed with the generous aid of Professor Basquin), which performs automatically the following cycle of operations:

1. Closes the arc circuit and lights the arc, thus heating the carbon electrodes and the region between them to a very high temperature.

2. After an interval of a few seconds, sufficient for the carbons to become thoroughly heated, interrupts the arc circuit.

3. After an interval which is less than one-tenth of a second, closes the spark circuit.

4. After a variable (but definite and measurable) interval of time, opens a shutter in front of the slit of the spectroscope and exposes the plate during any desired length of time, generally between ½ second and 1 second.

5. Interrupts the spark circuit.

1. Again closes the arc circuit; and so on, as before.

The arc was operated with 15 amperes showing 40 volts between the electrodes; while the spark was produced by a large induction coil of the type devised by Rowland in 1887 and described in Kayser's *Handbuch der Spectroscopie* (p. 183). This

induction coil, or step-up transformer, was operated on a 104-volt alternating circuit, of frequency 120, with a primary current of 20 amperes. In parallel with the spark gap was placed a capacity of $\frac{1}{500}$ microfarad. The arrangement of the circuit is shown in Fig. 2, where $S_1$ and $S_2$ are each double-pole mercury switches so fixed that *one can be closed only after the other is opened.* $S_1$ is kept closed by a spring until an electromagnet begins to close $S_2$ by rocking a light beam of which its armature is a part. The question of changing from arc to spark circuit is then merely a question of closing the battery circuit which actuates this electromagnet. This battery circuit is closed and opened by a continuously rotating switch (shown at the left in Fig. 3) which is driven at the uniform rate of 10 revolutions per minute by a small electric motor. This rate of rotation is maintained constant by means of a pair of cone pulleys and a heavy flywheel.

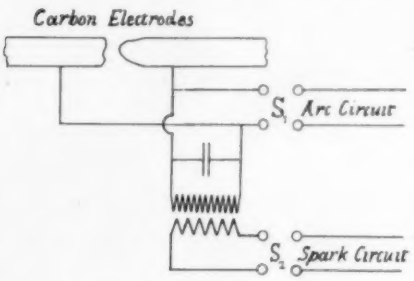



FIG. 2.

This same rotating switch, or commutator, by means of the sliding contact marked "2" in Figs. 3 and 5, opens the shutter in front of the slit of the spectroscope at any phase of the spark desired and holds the shutter open for a small but definite period of time varying usually from ½ second to 1 second. On this same rotating commutator shaft is a stud (*D*, Fig. 3) which, immediately after the arc circuit is closed, pushes a carbon rod into the arc gap for an instant and thus "lights" the arc.

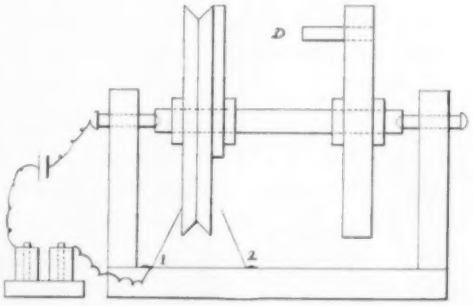



FIG. 3.

By clamping the sector $P$ (Fig. 5) to the rotating commutator in successive angular positions about its axis one is enabled to open the slit for the successive phases of the spark which he may wish to photograph; not only so, but he can repeat any phase as many times as he likes and thus obtain a strong composite in cases where a single exposure would produce no visible effect.

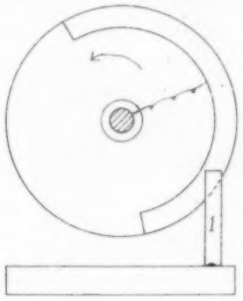



FIG. 4.

In this manner we have photographed the spark spectrum of carbon, with a ten-foot concave grating, in nine different phases[1] which may be roughly described as follows:

1. Exposure begins $\frac{1}{6}$ second after breaking arc and lasts $\frac{1}{2}$ second. Here the carbon poles are still white-hot and the spark is practically silent when compared with the noise which the cold spark makes. In this stage the luminosity is so exceedingly feeble that, with a slit of the same width as in the rest of the series, six to ten hours (*i. e.*, about 5,000 exposures) are required to get a fair negative.

2. Exposure begins $\frac{1}{4}$ second after breaking of arc and lasts for 1 second. The middle of the exposure, therefore, occurs $\frac{3}{4}$ second after the beginning of the spark. Here, again, the image of the spark on the slit of the spectroscope is quite invisible during the entire exposure.

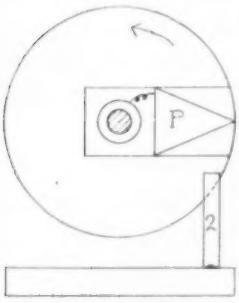



FIG. 5.

3. Exposure begins $\frac{1}{2}$ second after breaking of arc, and lasts for 1 second; middle of exposure 1 second after beginning of spark. Here the image of the spark is barely visible just before the slit is covered. The spark is distinctly louder than in the preceding phases.

4. Middle of exposure 1 $\frac{1}{4}$ seconds after beginning of spark.

5. Middle of exposure 1 $\frac{3}{4}$ seconds after beginning of spark.

6. Middle of exposure 2 $\frac{5}{8}$ seconds after starting spark.

7. Middle of exposure 5 $\frac{1}{4}$ seconds after starting spark. Here the electrodes begin to show merely red-hot instead of white-hot.

[1] The purpose of this experiment, it will be observed, is therefore fundamentally different from that in which Sir Norman Lockyer examined the spark spectra of salts volatilized in flames and which he described in *Proc. Roy. Soc.*, **30**, 22–31, 1879.

8. Middle of exposure 7⅞ seconds after beginning; spark distinctly noisy.

9. The last photograph in the series was taken at 12 seconds after the beginning of the spark, the duration of the exposure being, as in the preceding cases, 1 second. Even at this late stage a distinct *crescendo* is still noticeable in the noise of the spark.

The enormous increase of brilliancy from the hot spark to the cold may be judged from the fact that in order to make the cyanogen band at λ 3883 of uniform intensity the exposure time for the first of the series was 8 hours and for the last of the series 20 minutes.

## RESULTS.

As in the case of the Swan spectrum and the carbon arc, so also in the case of the carbon spark, the flutings are, of course, the dominant features of the entire spectrum. The first question, therefore, which naturally arises, in the development of the spark, is concerning the order and the relative intensity in which these cyanogen bands make their appearance. A second question might be asked concerning the stage at which the air lines make their appearance. A third query is, when and how do the numerous metallic impurities present themselves? Our photographs permit at least partial answers to these three questions for the region lying between λλ 4500 and 3000. The phenomenon is one which cannot be accurately observed by the eye: and the exposure times are so long as to render photographing in the visible region well-nigh impracticable.

1. *Carbon flutings and lines.*—The cyanogen bands at λλ 4216, 3883, and 3590 all make their appearance on the first photograph of the series. Their relative intensity is practically the same as in the case of the spark between cold electrodes, which, for the sake of brevity, we shall hereafter call the "cold spark." In view of this fact we have employed these three bands as standards of intensity; and have called any two spectra of "equal intensity" when these three bands were of equal intensities on the respective negatives. Each member of the series was, in this way, made of practically the same intensity.

As to the carbon lines, very few appear in this region. The line at λ 4556.3 does not appear in the hot spark, *i. e.*, in the earliest phase of the series described above. The broad, hazy line at λ 4267.5 which Eder and Valenta[1] call the "chief carbon line" disappears completely on introducing inductance into the circuit of the cold spark. And it does not appear at all in the hot spark. These two facts raise the question as to whether this line[2] is due to carbon. The line at λ 3361 persists in the hot spark; but it also appears in the aluminium spark and, greatly enhanced, in the copper spark when there is no capacity in the circuit. As to the remaining lines which Eder and Valenta describe in this region λλ 3920.8, 3877.0 and 3848.0, they are weak, and we have not been able to identify them to our satisfaction.

2. *Air Lines and Flutings.*— Not one of the ordinary air lines appears on any photograph whose phase is earlier than ¾ second. On the plate whose phase is ¾ second appear only the very heaviest of the air lines, viz., λλ 4630, 4447, 3995, 3433, 3330. Indeed the elimination of air lines is so complete in these earlier phases that non-appearance in the hot spark might be used as one criterion for air lines, analogous to the inductance test discovered by Schuster and Hemsalech.

As to nitrogen *flutings* which appear in spark spectra, when the electrodes are close together or when inductance is placed in series with the condenser, the case is very different — quite reversed, indeed — from that of ordinary air lines. The nitrogen flutings, with heads at λλ 3371.1 and 3158.7 respectively, come out very strong in the earliest phase; at ¾ second they begin to weaken; after 3 seconds, only a trace of them is left.

The nitrogen flutings of wave-length longer than 3371 do not appear in the spark under the conditions in which we are

[1] EDER and VALENTA, *Denksch. K. Akad.*, Wien, **60**, 249, 1893.

[2] The difference in behavior between this line at λ 4267.5 and the double red carbon line at λλ 6583 — 6577 leads Professor Schuster, on the basis of Herbert's experiments, to suggest that the red and blue lines may, at least, "belong to different spectra of carbon." *Note added Aug. 25, 1902.*

See *Phil. Mag.*, Aug. 1902, p. 207.

working, namely, a 3-millimeter spark gap in series with a condenser of $\frac{1}{500}$ microfarad capacity; no inductance.

We have not found any description of these nitrogen bands *as they appear in the spark spectra of elements in air at barometric pressure.* At first we took the band at λ 3371.1 to be a hitherto undescribed carbon band; and it was only through an excellent suggestion from Professor Hale that we discovered our mistake. He advised us to try the spark *without capacity.* On trying this experiment, we found the band at λ 3371.1 strongly present in spectra of aluminium, zinc, and other metals in air; but when the spark was worked in atmospheres of oxygen or coal gas, these flutings all disappeared save the merest trace of the strongest two.

The cold carbon spark (unlike that of metals) without capacity shows these bands only with extreme faintness; and the condensed carbon spark does not show them at all; the *carbon when white hot shows them strongly,* as indicated above.

In this connection, the question may be raised whether the band described by Professor Hutchins[1] does not belong to this nitrogen group. For we have found in the spark spectrum of aluminium a band, with its edge at λ 3914.41, which shows a weak line alternating with a strong one, exactly as in Hutchins' photograph. But on examining this spark in a current of oxygen, not the slightest trace of the band was found. Since it is found in metals, but not in the carbon spark, and since it disappears when nitrogen disappears, it seems to us more probably due to nitrogen[2] than to carbon.

[1] ASTROPHYSICAL JOURNAL, **15**, 310, 1902.

[2] Mr. F. J. Truby has measured the first fourteen lines of this fluting, which form a group lying between the edge and the heavy impurity line at λ 3905.74. His values are as follows:

| | | | |
|---|---|---|---|
| 3914.41 | head | 3909.95 | weak |
| 3913.89 | | 3909.30 | strong |
| 3913.35 | | 3908.52 | weak |
| 3912.62 | strong | 3907.80 | strong |
| 3912.17 | weak | 3906.88 | weak |
| 3911.70 | strong | 3906.16 | strong |
| 3911.17 | weak | 3905.74 | impurity |
| 3910.61 | strong | | |

There are possibly two other weak lines near the head which Mr. Truby's definition does not permit him to measure.

What is apparently the same band may be seen very distinctly on McClean's map of the spark spectrum of copper; and again a similar fluting has been found by Deslandres at the negative electrode of a spectrum tube filled with nitrogen. For Deslandres' drawing see *Comptes Rendus*, August 9, 1886. This is probably also the same band which is marked *very strong* at λ3914.4 in Hemsalech's[1] table of nitrogen bands. The fact that Hutchins is able to intensify the band he describes by making and breaking the arc circuit, would seem to indicate that it appears in the arc spectrum primarily in consequence of high electromotive force.

3. *Metallic impurities.*—The only electrodes which we have employed are the unplated, cored carbons, sold by A. T. Thompson, 25 Bromfield street, Boston, for use in projection lanterns. Their size is 7½ × ½ inches, and they are marked "imported." The metallic impurities which present themselves are practically only aluminium, calcium, copper, iron, and potassium. Possibly others might be detected by very long exposure or by study of portions of the spectrum other than that to which we have limited ourselves, namely, λ4500–λ3200. The strongest lines in this region of the hot-spark spectrum are two at λ4047.338 and λ4044.294 belonging to the principal series of potassium. They are faintly represented in the carbon arc; but *no trace of them can be found in the ordinary, or "cold," carbon spark.* Is it not rather surprising to find on a spark spectrum plate that the strongest lines are due not only to an impurity, but to an impurity which is introduced apparently by the condition of high temperature in the medium? For so far as the energy delivered by the spark itself is concerned, this would seem to be enormously greater in the loud and brilliant cold spark than in the quiet and invisible hot spark. We use the expression "high temperature" in this connection only with great hesitation, and then only with reference to the medium after the heating current has been cut off. *But this potassium pair persists very distinctly for five seconds after the heating* (*arc*)

[1] *Recherches Experimentales sur les Spectres*, etc., p. 126. (Paris, 1901.)

*current has been interrupted.* Accordingly, we find it difficult to imagine any electrical effect, other than heat, which would persist for this length of time, especially as the electrodes were placed always horizontally, so that strong convection currents were sweeping out anything in the nature of electrolytic products.

It seems not improbable that these effects of the hot spark are brought about through an increased conductivity—and, hence, a lowered electromotive force—between the poles of the spark gap, so that, in the series described above, the earlier phases partake of the character of the arc, while the later phases represent the spark. *If this be true, the nine members of this series of photographs constitute nine different steps between the arc spectrum and that of the spark.*

A similar diminution of E. M. F. between the hot poles is indicated by the work of Schenck,[1] who finds that, with hot poles, the "*Mg* spark line at λ4481 shrinks down close to the electrodes, while the arc triplet at λ5170 does not." And this view is rendered all the more probable by a fact noted by Professor Basquin,[2] viz., that an auxiliary cold spark gap in series with the hot spark gap suffices to render the spark lines immediately visible.

The general effect of the hot spark upon metallic impurities may perhaps be most clearly described in the following three statements:

1. Some *new* impurities are introduced, *e. g.*, potassium λλ4047.34, 4044.29, 3447.49, 3446.49. This is analogous to the introduction of the nitrogen fluting at λ3371 above mentioned.

2. Among lines *due to a single element* some may be diminished while others are enhanced in intensity. Thus the calcium pair at λλ3968.6 and 3933.8, and also the calcium pair at λλ3179.4 and 3159.0 are immensely diminished while the calcium line at λ4226.9 is so greatly enhanced by the hot spark that, after the potassium pair, it becomes the strongest in the

[1] Astrophysical Journal, 14, 131, 1901.

[2] Astrophysical Journal, 14, 15, 1901.

entire region studied. It is perhaps worth noting that all of the lines belonging to any one of Kayser and Runge's series are similarly affected. It would be interesting to know just how this behavior of potassium and calcium is explained in terms of the dissociation hypothesis.

3. The lines of some elements are affected either not at all, or very slightly, by the hot spark. This class is illustrated by the omnipresent copper pair at λλ 3274 and 3247; also by the aluminium pair between Fraunhofer's H and K; and by the great majority of the iron lines.

In general, it may be noted that there is nothing in the nature of a sudden change anywhere in the series. Indeed, the growth of the air lines and the diminution of certain impurity lines is so gradual and definite that one might use their relative intensities to determine the phase at which any particular photograph was taken. The triplet formed by the potassium pair at λλ 4047 and 4044, together with the strong iron line between them, serve to illustrate this principle and also to point out an exception

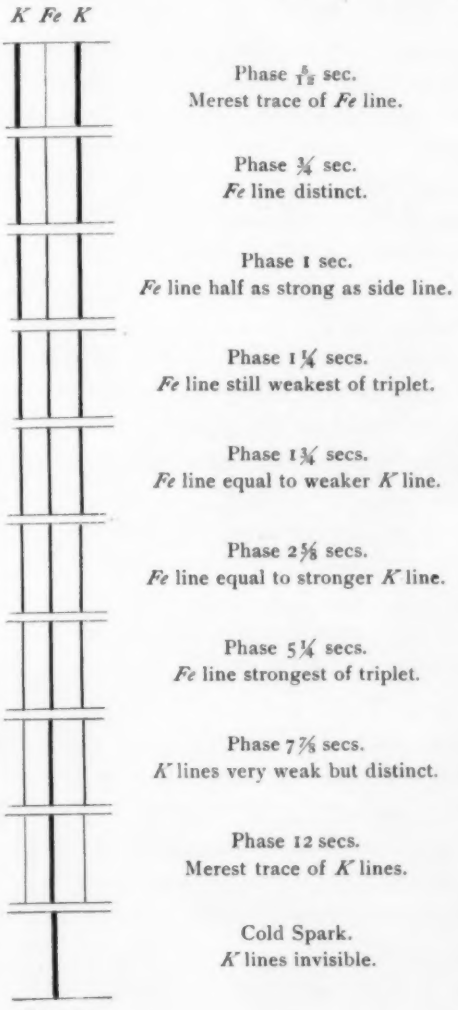

K Fe K
Phase 5/12 sec.
Merest trace of Fe line.
Phase ¾ sec.
Fe line distinct.
Phase 1 sec.
Fe line half as strong as side line.
Phase 1¼ secs.
Fe line still weakest of triplet.
Phase 1¾ secs.
Fe line equal to weaker K line.
Phase 2⅝ secs.
Fe line equal to stronger K line.
Phase 5¼ secs.
Fe line strongest of triplet.
Phase 7⅞ secs.
K lines very weak but distinct.
Phase 12 secs.
Merest trace of K lines.
Cold Spark.
K lines invisible.

FIG. 6.

to the rule that the iron lines are generally unaffected by the hot spark. For, curiously enough, *this iron line increases* in intensity as the spark-gap (the medium) cools down, while, as noted above, *the potassium pair diminishes* with the temperature. In this comparison the three cyanogen bands are taken as the standard of intensity, and have essentially the same density on each plate. The triplet thus assumes the successive appearances shown in the accompanying figure. If we had measured the temperature of the region between the carbon poles at each of these nine phases, we could have identified with certainty each of these temperatures from the appearance (relative intensity) of the triplet. It is not to be forgotten that the temperature here referred to is *not* the much-talked-of and little-understood "temperature of the spark;" nor is it any temperature peculiar to certain "streaks," as perhaps is the case in the Geissler tube discharge. The temperature here referred to is that of the medium at the instant in which the shutter of the spectrograph is opened. The appearance of this triplet is then a criterion for a temperature, which may be measured directly with a thermo-electric couple of sufficiently fine wire; it is a function of the phase, and not of the duration, of the exposure.

NORTHWESTERN UNIVERSITY,
Evanston, Ill., July 19, 1902.

# THE ABSORPTIVE POWER OF THE SOLAR ATMOSPHERE.[1]

By FRANK W. VERY.

THE observations on which the present paper is founded were made at the Allegheny Observatory in the summer of 1882. Their original purpose was to furnish a test of Professor Langley's well-known theory of the "blue Sun." A concise account of the preliminary results appeared in a letter to *Nature* (**36**, 76, May 26, 1887), by Professor S. P. Langley, in which the bearing of the measurements of absorption by the atmospheres of the Sun and the Earth on this particular question were summed up in the general statement that, if we could view the naked photosphere of the Sun, it would appear of a violaceous or lavender tint.

The interpretation of the measures, as far as they affect our knowledge of the law of absorption by the solar atmosphere, still left much to be desired, and it is only recently that I have been able to get anything like a satisfactory conception of the absorptive process.

## MEASUREMENTS OF RADIATION OF DIFFERENT WAVE-LENGTHS COMING FROM DEFINITE REGIONS OF THE SOLAR DISK.

The apparatus consisted of the achromatic glass lens of the great equatorial, 464 cm in focal length (aperture limited by the small size of the heliostat mirror to 16 cm), used in conjunction with a horizontal meridional heliostat, forming a solar image 4.27 cm in diameter upon the white-paper facing of the slit-plate of a spectro-bolometer. By pulling the guiding cords of the horizontal movement of the heliostat, the edge of the solar image could be easily and rapidly brought to tangency with fine lines, ruled on the white paper, and numbered, each position corresponding to a definite fraction of the radius of the solar disk falling upon the slit.

[1] Communicated by F. L. O. Wadsworth, Director Allegheny Observatory.

The spectroscopic outfit consisted of a glass prism, made by Hilger, with short focus glass lenses accurately adjusted for the particular point in the spectrum chosen for measurement. To get absolute values, corrections for absorption by the glass of four lenses and one prism, and for loss by reflection from silver would need to be applied. For these relative measurements, however, this is unnecessary, since each set of measures was made under constant instrumental conditions. The bolometer was 2 mm wide, and included successively seven groups of rays whose mean wave-lengths were: 0.416$\mu$, 0.468$\mu$, 0.550$\mu$, 0.615$\mu$, 0.781$\mu$, 1.01$\mu$, 1.50$\mu$. The width of the slit varied between 0.2 mm and 0.4 mm, or from one-fifth to one-tenth the width of the bolometer, but in no case were any rays included whose source differed by more than one one-hundredth of the solar radius from the mean position chosen, except in so far as the occasional quivering of the image, produced by irregular refraction, may have momentarily thrown into the slit, rays from neighboring solar regions. Unfortunately, the accuracy which appertains to the verification of the position of the slit in the solar image, cannot be predicated in like degree of the thermal measures, which remain affected by all the fluctuations of our perpetually changing atmosphere, whose transmissive power varies from moment to moment. In order to secure the most reliable determinations of solar atmospheric transmission, and to eliminate, as far as possible, those errors produced by changes in the telluric absorption, it is desirable to make the measures rapidly and to secure a considerable number of comparisons. Accordingly, a particular fraction of the solar radius, and a particular wave-length having been selected, comparisons of heat at this point and at the center were made alternately, first on the east side, and immediately after on the west. Each marginal measure was then compared with the mean of the preceding and following ones on the center.

Two examples are given in full, one for minimum deviation $50° = \lambda 0.416\mu$ in the violet, and one for minimum deviation $48° = \lambda 0.550\mu$ in the citron. At each fraction of the radius are

given the galvanometer deflections observed, and the ratios of the deflections at stated points to those at the center found in juxtaposition.

TABLE I.

| Violet, $\lambda$=0.416 $\mu$ | 0.50 $r$ | | 0.75 $r$ | | 0.95 $r$ | | 0.98 $r$ | |
|---|---|---|---|---|---|---|---|---|
| | Defl. | Ratio | Defl. | Ratio | Defl. | Ratio | Defl. | Ratio |
| | div. | | div. | | div. | | div. | |
| Center | 26 | ..... | 23½ | ..... | 24 | ..... | 38 | ..... |
| East | 21¾ | 0.837 | 18 | 0.747 | 11½ | 0.500 | 9½ | 0.253 |
| Center | 26 | ..... | 24¾ | ..... | 22 | ..... | ..... | ..... |
| West | 21½ | 0.833 | 17½ | 0.726 | 10½ | 0.465 | 11½ | 0 307 |
| Center | 25½ | ..... | 23½ | ..... | 23¼ | ..... | 37 | ..... |
| East | 22½ | 0.882 | 17½ | 0.745 | 11½ | 0.502 | 11 | 0.297 |
| Center | 25½ | ..... | 23½ | ..... | 22½ | ..... | ..... | ..... |
| West | 21½ | 0.878 | 18 | 0.756 | 9½ | 0.417 | 11 | 0.297 |
| Center | 23½ | ..... | 24 | ..... | 23 | ..... | 37 | ..... |
| Mean ratio, August 24 | ($3^h$ 35$^m$) | 0.858 | ($3^h$ 45$^m$) | 0.744 | ($3^h$ 55$^m$) | 0.471 | ($2^h$ 8$^m$) | 0.289 |
| Calculated transmission by unit depth of atmosphere | ..... | 0 372 | ..... | 0.561 | ..... | 0.710 | ..... | 0 735 |

| Citron, $\lambda$=0.550 $\mu$ | 0.50 $r$ | | 0.75 $r$ | | 0.95 $r$ | | 0.98 $r$ | |
|---|---|---|---|---|---|---|---|---|
| | div. | | div. | | div. | | div. | [0.478] |
| Center | 366½ | ..... | 345½ | ..... | 383 | ..... | 310 | [0.536] |
| East | 348 | 0.956 | 300 | 0.836 | 213 | 0.559 | 124 | 0.423 |
| Center | 361¼ | ..... | 372 | ..... | 380 | ..... | 275½ | ..... |
| West | 324 | 0.903 | 302 | 0.822 | 223¼ | 0.581 | 146 | 0.498 |
| Center | 357 | ..... | 363 | ..... | 389 | ..... | 310 | ..... |
| East | 347 | 0.940 | ..... | ..... | ..... | ..... | ..... | ..... |
| | 354 | 0.959 | 312 | 0.841 | 232 | 0.599 | 156 | 0.481 |
| Center | 381 | ..... | 378 | ..... | 385 | ..... | 338 | ..... |
| West | 332½ | 0.908 | 314 | 0.824 | 230 | 0.610 | 159 | 0.485 |
| Center | 352 | ..... | 383 | ..... | 368½ | ..... | 317½ | ..... |
| Mean ratio, September 2 | ($1^h$ 20$^m$) | 0.933 | ($1^h$ 45$^m$) | 0.831 | ($1^h$ 55$^m$) | 0.587 | ($3^h$ 35$^m$) | 0.484 |
| Calculated transmission by unit depth of atmosphere | ..... | 0.640 | ..... | 0.697 | ..... | 0.785 | ..... | 0.835 |

The last line of Table I gives the transmission by a unit of the solar atmosphere (meaning by this the radial depth of the gaseous layers lying above the photosphere), computed by the ordinary secant formula. As in the case of the absorption of radiation by the Earth's atmosphere, it is obvious that there is considerable departure from the assumed law, and that with increasing depth of the absorptive layer the apparent transmission, by unit depth, derived in this manner, is not a constant, but becomes progressively greater in both cases, although possibly not from the same cause.

It will be seen that at every radial position without exception, the radiation falls off in the direction of the Sun's limb, and does so quite rapidly. No marked difference could be detected between the heat at similar radial positions on the east

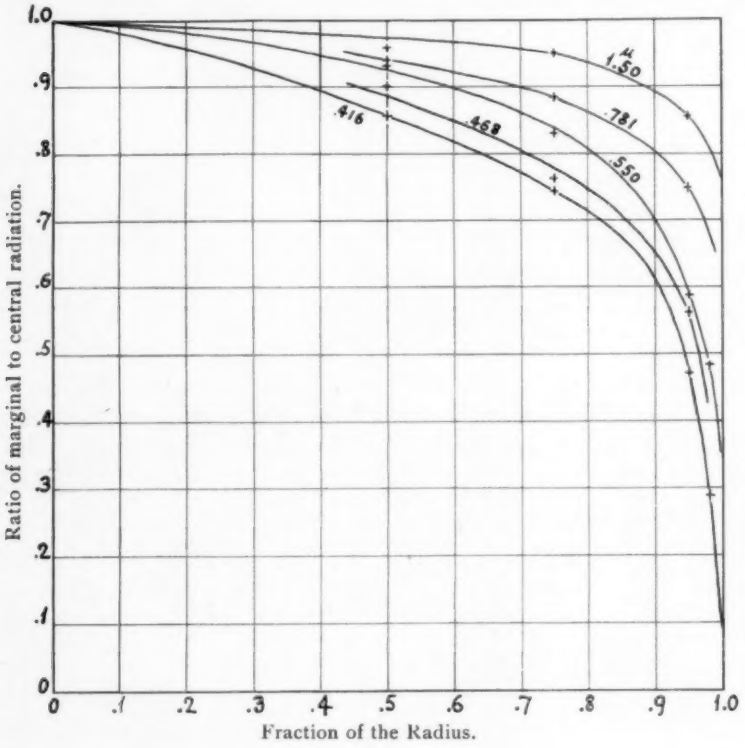



FIG. 1.

and west limbs; and Langley had previously proved that the thermal effect of the total or combined radiations from corresponding points on the north, south, east, and west limbs, as registered on a thermopile, is practically identical. See the paper "Sur la température relative des divers régions du soleil. 2me partie: Région équatoriale et régions polaires," *Comptes Rendus*, **80**, 819, 1875. Also another paper: "Étude des radiations superficielles du soleil," *ibid.*, **81**, 436, 1875, from which I

take the following results, stated as percentages of the total radiation from the center of the solar disk:

| | N. | E. | S. | W. | Mean |
|---|---|---|---|---|---|
| .50 *r* | 94.9 | 94.7 | 94.5 | 95.9 | 95.0 |
| .75 *r* | 86.5 | 85.6 | 85.5 | 84.0 | 85.9 |
| .96 *r* | 60.7 | 60.6 | 62.3 | 63.9 | 61.9 |
| .98 *r* | 50.8 | 47.7 | 49.5 | 52.2 | 50.1 |

The measures may therefore be presented in the form of a diagram in which the solar disk is divided into concentric annuli, to be regarded as contour lines exhibiting the varying thermal efficiency of different parts of the Sun's surface in the form of a symmetrical elevation; or, better, the varying radiation may be displayed as a series of sections of such thermal diagrams for particular regions of the spectrum. Curves showing these relations are presented in Fig. 1, which shows the more rapid diminution of the radiations of shorter wave-length in the direction of the Sun's limb, in comparison with the falling off of the longer waves. A tabular view of the mean results of these observations follows:

TABLE II.

Ratios of Marginal to Central Radiation.

| λ = | 0.416 μ | 0.468 μ | 0.550 μ [1] | 0.615 μ | 0.781 μ | 1.01 μ | 1.50 μ |
|---|---|---|---|---|---|---|---|
| Deviation | 50° | 49° | 48° | 47° 30′ | 46° 45′ | 46° 12′ | 45° 28′ |
| 0.98 *r* | 0.289 | ..... | 0.484 | ..... | ..... | ..... | ..... |
| 0.95 *r* | 0.471 | 0.462 | 0.587 | 0.681 | 0.749 | 0.765 | 0.856 |
| 0.75 *r* | 0.744 | 0.764 | 0.831 | 0.845 | 0.885 | 0.894 | 0.950 |
| 0.50 *r* | 0.858 | 0.902 | 0.933 | 0.948 | 0.941 | 0.943 | 0.959 |

The only measures with which these can be compared are those of Dr. H. C. Vogel with a spectro-photometer. These give smaller ratios at the red end of the spectrum for the position 0.95 radius: violet 0.347, blue 0.456, green 0.440, yellow 0.460, red 0.580. The bolometer has an advantage over the eye in the red where the heat is great.

Repeated measures across the spectral regions where some of the great infra-red cold bands lie, proved that these absorption bands are not produced by the solar atmosphere, but since the bands broaden and deepen as the Sun goes down, they are unquestionably telluric. The absorption indicated by the marginal diminution of radiant intensity is of another order. I proceed to the further consideration and interpretation of these results.

## THEORY OF THE ABSORPTION OF RADIATION BY THE SUN'S ATMOSPHERE.

If we compute coefficients of transmission, assuming uniform original radiation, and adopting the hypothesis that successive equivalent layers absorb equal fractions of the rays entering them, the striking result is obtained that the marginal measures appear to indicate a more highly transmissive atmosphere than those measures nearer the center, as shown in the final line of Table I. Asking now the meaning of this, let

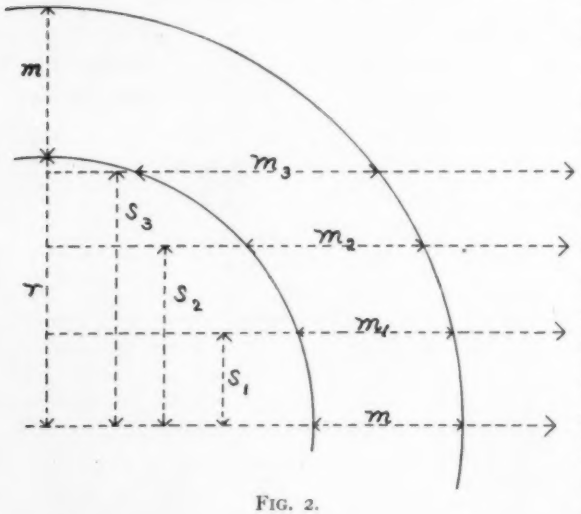



FIG. 2.

$m$ (Fig. 2) be the thickness of the solar atmosphere, assumed to be homogeneous; $r$ = the Sun's radius; $p$ = the transmission through a radial section of this solar envelope; and let $s_1$, $s_2$, $s_3$, be distances from the center of the solar disk to the points on the

[1] Other series at wave-length 0.550 $\mu$, omitting he readings at 0.98 of the radius, gave the following concordant results, scarcely differing except at 0.95 $r$: at 0.95 $r$, 0.618; at 0.75 $r$, 0.827; at 0.50 $r$, 0.936.

disk selected for measurement (expressed as fractions of the photospheric radius, $r$, which may be taken to be unity). Then $r + m = 1 + m$ will be the radius of the outer limit of the effective solar atmosphere. Let $m_1$, $m_2$, $m_3$, be the atmospheric paths of rays starting from the photosphere at distances $s_1$, $s_2$, $s_3$, from the center of the solar disk, and emitted in the direction of the Earth; and let $R_1$, $R_2$, $R_3$, be the ratios of the energy of these rays compared with central ones, or the values given in Table II. Then, other things being equal, if successive layers repeat the absorbent process according to the same law, and none of the rays vanish,

$$p = R_1^{\frac{1}{m_1 - m}} = R_2^{\frac{1}{m_2 - m}} = R_3^{\frac{1}{m_3 - m}} . \qquad (1)$$

The relative masses or depths of absorbent atmosphere in the several cases are to be computed by the equations:

$$m_1 = \cos\left(\sin^{-1}\frac{s_1}{1+m}\right) - \cos\left(\sin^{-1} s_1\right) ,$$

$$m_2 = \cos\left(\sin^{-1}\frac{s_2}{1+m}\right) - \cos\left(\sin^{-1} s_2\right) ,$$

$$m_3 = \cos\left(\sin^{-1}\frac{s_3}{1+m}\right) - \cos\left(\sin^{-1} s_3\right) .$$

In the first treatment of the problem, the unknown quantities being $p$ and $m$, I shall assume the photospheric radiation to be equal for all parts of the disk. Since the values of $p$ and $m$ must then satisfy equation 1, it becomes possible, on this assumption, to infer the resulting depth of the efficient solar atmosphere. Omitting the observations at the violet end of the spectrum, which, on account of spectral non-homogeneity, may follow a different law, five wave-lengths remain for which transmissions are computed from the ratios of central, intermediate, and marginal radiations by the preceding formulæ: first (*a*) assuming an atmosphere of little depth; second (*b*) assuming an atmosphere whose depth is one half the radius of the sphere; and third (*c*) assuming an atmosphere whose depth is equal to the radius.

From measures at the center combined with those at the positions: $0.50r$ $0.75r$ $0.95r$

(*a*) For $m = \frac{r}{\infty}$, $m_1 - m = 0.155$, $m_2 - m = 0.512$, $m_3 - m = 2.202$.

(*b*) For $m = \frac{r}{2}$, $m_1 - m = 0.096$, $m_2 - m = 0.270$, $m_3 - m = 0.698$.

(*c*) For $m = r$, $m_1 - m = 0.070$, $m_2 - m = 0.192$, $m_3 - m = 0.446$.

TABLE III.

| Position = | $0.50r$ | | | $0.75r$ | | | $0.95r$ | | |
|---|---|---|---|---|---|---|---|---|---|
| $\lambda$ | *a* | *b* | *c* | *a* | *b* | *c* | *a* | *b* | *c* |
| $0.550\mu$ | 0.652 | 0.501 | 0.388 | 0.690 | 0.494 | 0.371 | 0.803 | 0.501 | 0.339 |
| 0.615 | 0.708 | 0.573 | 0.466 | 0.719 | 0.535 | 0.415 | 0.840 | 0.576 | 0.422 |
| 0.781 | 0.676 | 0.531 | 0.420 | 0.788 | 0.636 | 0.529 | 0.877 | 0.661 | 0.523 |
| 1.01 | 0.683 | 0.540 | 0.429 | 0.803 | 0.659 | 0.556 | 0.885 | 0.681 | 0.548 |
| 1.50 | 0.763 | 0.646 | 0.550 | 0.904 | 0.827 | 0.765 | 0.932 | 0.800 | 0.706 |
| Mean $p$ | 0.696 | 0.558 | 0.451 | 0.781 | 0.630 | 0.527 | 0.867 | 0.644 | 0.508 |

| | |
|---|---|
| Mean transmission | (*a*) 0.781 |
| " " | (*b*) 0.611 |
| " " | (*c*) 0.495 |

The smaller transmissions of series (*b*) and (*c*), derived from measures at different radial positions, are more nearly accordant than those of series (*a*), and this, in the absence of any other explanation, would favor the doctrine of a solar atmosphere of great depth, substantially coinciding with the solar corona, rather than with the chromosphere. Nor need the hypothesis be dismissed as entirely impossible, since the peculiar law of solar atmospheric absorption coincides with that progressively increasing selective reflection which the floating particles and even the air molecules of our atmosphere exert on the shorter waves of light.

### EFFECT OF DIFFRACTION BY FINE PARTICLES.

As the corona contains some scattered dust, a diffraction effect is possible, indeed it certainly exists, and the only question is as to its quantitative value. Professor C. D.

Perrine has found that the inner corona, to a height of 2′ to 8′, gives a continuous spectrum, such as might be produced by incandescent solid particles floating in the lower and denser layers of the solar atmosphere; but that above this zone, the coronal light is reflected sunlight showing the Fraunhofer lines. ("Preliminary Report of Observations of the Total Solar Eclipse of 1901, May 17–18," by C. D. Perrine; ASTROPHYSICAL JOURNAL, **14**, 349, December 1901.) Above this lower zone and to a height of half a degree, "comparisons with a sky spectrogram secured with the same instrument show that the coronal and sky spectra are sensibly identical in the blue and violet regions" (p. 354). Polariscopic observations also show that the light from the outer corona agrees with that of the sky in being polarized, and consequently we may assume that the coronal envelope, like the Earth's atmosphere, contains finely divided matter competent to either reflect or diffract sunlight, dispersing it in all directions, and acting upon the photospheric radiation selectively, that is, sending off a relatively larger percentage of the shorter rays.

It is somewhat difficult to judge by the eye in regard to the color of a faint light. Eclipse observers will probably agree that the coronal light appears almost white, or if it possesses any color this must be faint; but the spectrogram, it seems, decides the point in favor of a blue-tinted corona, with a light resembling that of the sky, and supplements the evidence derived from the colors of the solar image (reddish-brown near the limb and bluish at the center), as well as that from the spectro-bolometric comparisons along a radius of the solar disk, all declaring that the Sun is surrounded by a medium which excessively depletes the composite beam of its shorter waves and disseminates them in all directions as a feeble coronal illumination. If we accept Lord Rayleigh's theory that the blue light of the sky is diffracted by the air molecules, we must conclude that the corona is subdivided to molecular dimensions. Huggins, in his Bakerian lecture of 1885, arrived at an analogous conclusion, deciding that the coronal substance is so highly attenuated that

its particles, like those of comets' tails, are more strongly affected by electric repulsion than by gravitational attraction. Nevertheless, there must be a lower limit to the fineness of the coronal particles which give the polarized light, because a Bunsen flame does not reflect sunlight unless, by partial deprivation of air, the flame begins to assume an illuminating quality. If an image of the Sun be formed by a condensing mirror in the midst of a luminous or partially luminous flame, a brilliant blue light is emitted in all directions from the focal point, and is found to agree with sunlight in color, presence of Fraunhofer lines, and polarization. This light is sunlight which has been selectively reflected from solid particles of carbon, perhaps only a little larger than molecules, at any rate of excessively minute dimensions.

The corona appears to contain particles of some such magnitude, which probably diminish in size as the distance from the photospheric, or incandescent cloud surface, increases, until, at a considerable radial distance, they cease to diffract any but the shorter waves of sunlight. Dr. C. G. Abbot concludes from his bolometric measures of coronal radiation in the eclipse of May 28, 1900, that the corona seems "to be giving light in a manner not associated with a high temperature, or at least with the preponderance of infra-red rays usual in the spectra of hot bodies" (ASTROPHYSICAL JOURNAL, **12**, 73, July 1900). The preponderance of short waves and almost complete absence of infra-red rays in the coronal radiation is consistent with the supposition that the corona itself may be the medium which depletes the solar rays of their shorter waves. Coarser incandescent particles may diffuse as well as radiate the longer waves, but such particles probably only exist at low levels, where their presence has indeed been demonstrated by Campbell's spectrograms at the Indian eclipse of 1898, and inferentially by the continuation of selective depletion of radiation by the solar atmosphere as far as bolometric measures have been made in the infra-red spectrum.

We can subject the hypothesis of an extensive envelope,

depleting the rays by selective diffraction, to a further test by comparing the light diffused by the corona with direct sunlight. Suppose that three-fourths of the direct solar light is selectively reflected. An amount of light three times as great as that which reaches us directly from the Sun, is then diffused by some part of the corona lying between us and the photosphere, and is distributed over more than a hemisphere. Perhaps the fraction $\frac{3}{120000}$ might be taken as a rude approximation to the dilution of the light by this process. Now, during an eclipse of the Sun, the coronal light at 1′ from the Moon's limb has been found to have six times the intrinsic brightness of the Moon (*Washington Observations* for 1876, Appendix III, p. 214), and moonlight is about $\frac{1}{600000}$ of the intensity of sunlight. The luminosity of the corona also falls off very rapidly in a radial direction. At some point not much within the 1′ limit, the coronal luminosity is fifteen times brighter than moonlight, or in the ratio of the above fractions, and from a still narrower ring the proportion of light is much greater; but the light of the outer corona represents only a small fraction of the total loss of sunlight by selective reflection. The principal part of the diffusive action is due to the inner layers of coronal substance, and the efficient depleting atmosphere is at any rate confined practically to those regions which are sometimes called "the inner corona," constituting a very bright annulus 0′.5 or 1′.0 broad, as seen at the times of total solar eclipse, and even here the effect is greatest for the lowest levels.

### EFFECT OF ATMOSPHERIC STRUCTURE.

Another possible explanation of the greater apparent transmission near the Sun's limb is that it results from the action of irregularly distributed ingredients in the solar atmosphere upon the transmitted sunbeam. Suppose that this atmosphere has a columnar structure, certain absorbent gases, or substances which deplete the rays, whether by absorption or by selective reflection, existing in isolated vertical currents in the midst of other inert

substances which may be more regularly distributed. Such a structure is indicated by some visible appearances, such as the serrations of the chromosphere and the penumbral filaments in Sun-spots; and as far as it exists, it must make itself felt in the nature of its absorptive effects. Let the height of these columns be ten times their diameter, and let us assume that they are radially distributed over the spherical surface, occupying one-fifth of its area (Fig. 3). Indicating by $p_1$ the coefficient of transmission through a layer of absorbent substance equal in depth to the average diameter of a column, if $p_1 = 0.9$, for central position and columnar structure, the photospheric radiant energy ($P$) escaping through the atmosphere is $0.8\,P + 0.2\,(p_1)^{10} \times P = 0.87\,P$, a larger quantity than would result if the same amount of absorbent material were spread horizontally in a layer of depth $= 2$, giving for central position and stratal structure, radiant energy transmitted $= (p_1)^2 \times P = 0.81\,P$.

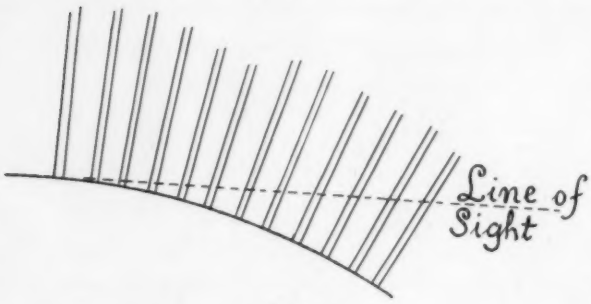



FIG. 3.

Consider now the effect on a ray from the edge of the visible solar disk, which has passed transversely through ten such columns. The intracolumnar path will differ but little from an intrastratal one, if the atmosphere be of slight depth relatively to the radius. Ruling out the hypothetical atmosphere of great depth, the marginal radiation transmitted is $(p_1)^{10} \times P = 0.35\,P$. Erroneously computed from the central value, supposed to be known, a smaller marginal value, $(0.87)^{10} \times P = 0.25\,P$, is obtained, or in appearance the marginal atmosphere is more transparent than the central. The effect of columnar structure in an atmosphere is therefore similar to that produced by greater depth, or by that selective absorption and extinction of individual rays which leaves the emergent beam more and more transmissible by succeeding layers of the same absorbent.

The Earth's atmosphere partakes of the same properties. Sudden variations in solar radiation measured by an actinometer of rapid registry, like Crova's, occur under a clear sky, and are of much wider range with high than with low Sun. In the middle of the day, the rays sometimes penetrate *between*, and sometimes *through* the absorbent columns for nearly their whole length, thus causing great and sudden variations; while, with a low Sun, the number of columns intersected does not vary greatly, and the solar radiation does not fluctuate so much. The effect is greatest in summer when ascensional movements of the air are most powerful, and it makes the summer air appear more transparent than that of winter, although the reverse is really the case, aqueous vapor, which is more prevalent in summer, being the chief absorbent among the constituents of the Earth's atmosphere.

Consider only the part of the general depletion of the sunbeam which is effected by selective reflection. If this exhibits any tendency to depart from a logarithmic law dependent on the depth of air penetrated by the rays, it must be on account of atmospheric columnar structure, and an irregular distribution of fine haze, perhaps constituted of incipient watery mist, which, in turn, owes its existence to the atmospheric movements which have produced the structure. But a large part of the discrepancy between transmissions computed from observations with different air-depths, results from a progressive disappearance of rays or particular wave-length in the upper air, mainly through absorption by aqueous vapor. In other words, the summer air, as well as the longer air-column traversed by the rays at low Sun, transmits the residual of a sifted solar radiation somewhat readily; but it does this because a larger number of the incoming homogeneous rays has been completely removed in the upper air. Locally selective absorption is of less importance in producing variation of apparent transmission by the solar atmosphere, because the Fraunhofer lines, especially in the infra-red, are nowhere so intense nor productive of such crowded arrangements into broad bands, as are the aqueous lines which chiefly concern telluric atmospheric absorption.

EFFECT OF PHOTOSPHERIC IRREGULARITY.

Quite apart from the distribution of the absorbent constituents of the outer solar envelopes is another factor which requires recognition, namely, the irregularity of the radiating photospheric surface. This irregularity will have but little influence on the apparent transmissive power of the solar atmosphere if the latter is exercised by an envelope of great depth; but if all, or even a considerable part of the absorption is produced by the Sun's reversing layer, which is a stratum of comparatively slight depth, or even by an atmosphere as deep as the chromosphere, or the inner part of the inner corona, a marked effect must follow from the *form* of the radiating surface.

The photosphere is made up of brilliant "rice-grains" and their component "granules," separated by a relatively dark reticulation in which the light having come from greater depths, suffers larger absorption than where it proceeds from the summits of the photospheric clouds, or granules. Langley, who discovered the granules, estimated them to occupy one-fifth of the surface at the center of the Sun's disk; but near the limb the light must come mainly from cloud summits, the bases being hid. Some of Janssen's photographs give even smaller ratios for the luminous dots. Assuming that the light at 0.95 of the radius comes entirely from granules which occupy but one-fifth of the surface at the center, the following estimate of intensities was made:

A drawing, which was considered fairly representative of the relative depth of light and shade in the rice-grain structure, was compared with a pair of black and white Maxwell's disks revolved with sufficient rapidity to produce a gray which could be matched with the shading on the drawing. The darker shading was equal to a gray of ⅛ white, ⅞ black; the lighter was equivalent to a gray of ¼ white, ¾ black. Adopting an average gray of ⅙ white, we have for central light,

$$L_c = 0.2 + (0.8 \times \tfrac{1}{6}) = 0.333 ,$$

and for light from the margin,

$$L_m = 1 .$$

Calling photospheric radiation from the center $P$, and taking the mean of the ratios at $0.95r$ for the five wave-lengths given in Table III with the exponent ($m_3$) appropriate to condition ($a$) we have:

$$\text{Central radiation} = P \times p = 1000,$$
$$\text{Marginal radiation} = 3P \times (p)^{3.2} = 734,$$

whence the coefficient of transmission is $p = 0.527$, which may be compared with the mean, $p = 0.495$ for an atmosphere of radial depth.

RESULTS OF A COMPARISON OF THE THEORY WITH THE OBSERVATIONS.

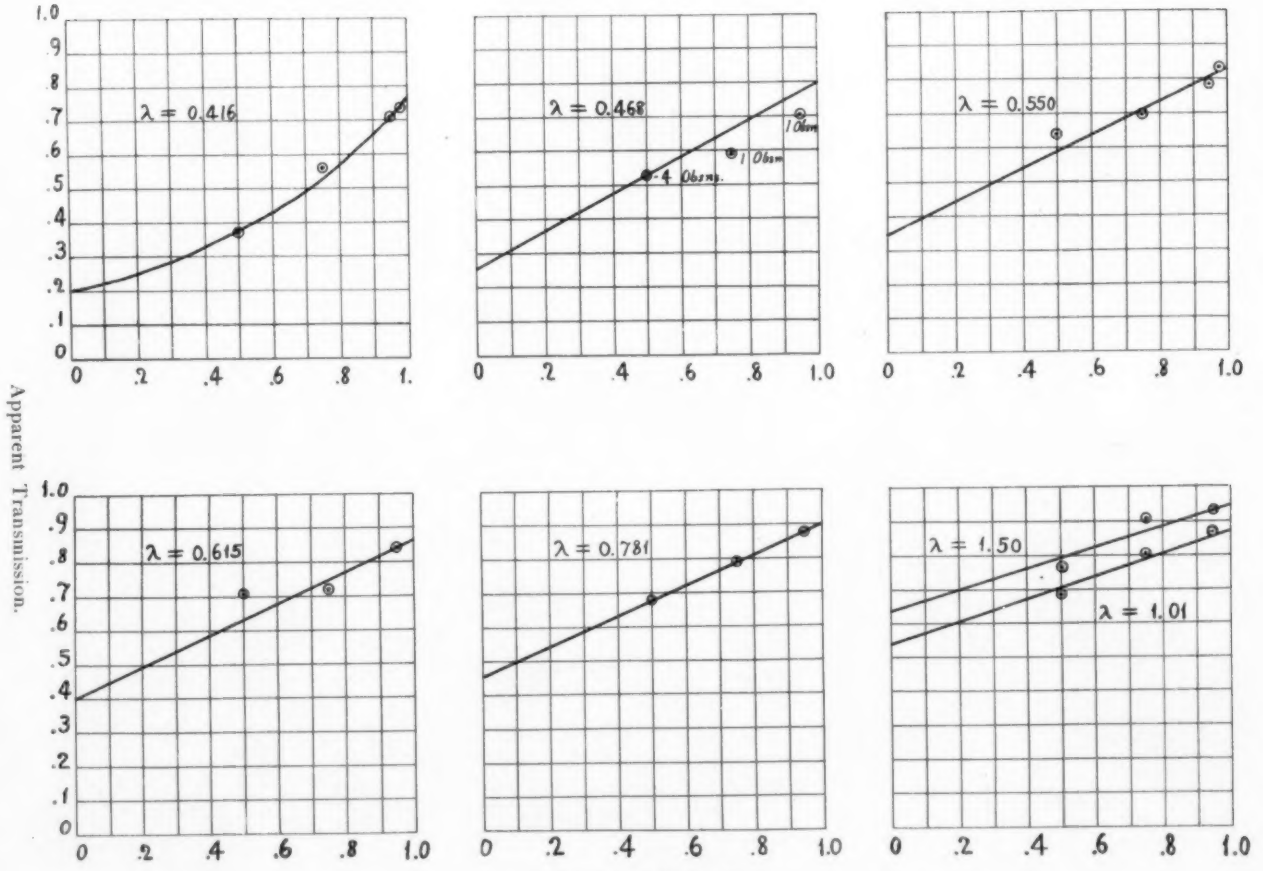
The result is that whether we attribute the discrepancies in the coefficients of solar transmission for radiation from different points of the disk to great depth of the solar atmosphere, or to increased photospheric brilliancy at the limb, the effect on the calculated transmission is similar. It is evidently necessary to diminish all of the computed coefficients of transmission, those from the marginal measures being reduced in greater proportion, and since the progressive extinction of particular spectral rays in the marginal radiation still further increases the effect, I think we may safely infer that not more than one-half of the red and infra-red radiation of the photosphere, is able to penetrate the solar atmosphere, while still less of the violet and ultra-violet gets through. It will be observed that the three causes of variation in the coefficients of transmission computed by the secant formula all act in the same direction, and all appear to be real.

Comparing the effects of increasing photospheric brilliancy towards the limb, and of great depth of solar absorbent envelopes, we find difficulty in separating them, because neglect of either action makes the calculated transmissions appear too large by similar amounts, the result being further complicated by our ignorance of the precise alteration effected by the peculiar structure of the Sun's outer envelopes. The form of the calculated transmission-curves from center to limb gives, however, a means of separating the influence exerted by the lack of homogeneity in the spectrum.

The exponential formula which is commonly used in the reduction of observations for atmospheric transmission has the form of the logarithmic curve whose equation is $y = a^x$ ; or if $A$ is the radiant energy which passes through the solar atmosphere, $P$ the original photospheric radiation, $m$ the mass of the solar media through which the rays pass, and $p$ the coefficient of transmission through the solar media, $A = P \times (p)^m$, where $P$ and $p$ are supposed to be constants. If the formula were followed, therefore, we should get the same value of $p$ from observations at all points of the solar disk, or if we plotted them, letting abscissae be the fractions of the solar radius, and ordinates be the corresponding values of $p$ derived by comparison of energies at these points with that at the center, the values of $p$ should lie on a straight line parallel to the axis of $X$. If, however, some unknown action, increasing or decreasing from center to margin according to some regular law, is at work, our calculated values of $p$ may follow a curve of some different shape. Still, if we could determine the form of this curve, the point at which it cut the axis of $Y$ (ordinate at the Sun's center) would give us the value of $p$ which we are seeking, namely, that for radial transmission through the solar atmospheric envelope. A considerable number of observations renders it nearly certain that the form of the above curve for $p$ is a straight line inclined to the axis at such an angle that for the middle rays of the spectrum it would meet the axis of $Y$ at about $p = 0.5$, while for ultra-violet rays the intersections fall very near zero, and for extreme infra-red rays exceed 0.5, but fall below 0.9. These, therefore, are the real coefficients of transmission.

The curves of computed transmission from center to edge (Plate III) do not depart appreciably from inclined straight lines, except in the case of the violet rays. For these, however, the curvature is marked; that is, the apparent transmission of violet rays ($\lambda = 0.416\mu$) not only increases with the radius of the point of departure, but at an increasing rate. This suggests that the increment of locally selective absorption of violet light, indicated by the crowded Fraunhofer lines in this part of the spec-

PLATE III.




Computed Transmissions from Center to Edge.

trum, is accompanied by the successive vanishing of particular rays which drop out and leave a more transmissible beam of sifted marginal radiation. The percentage of vanished rays may possibly be estimated by the departure of the curve from a straight line (perhaps 10 per cent. for marginal violet rays). The general depletion by selective reflection or diffraction also increases in the direction of the shorter waves, and the combined effect produces complete extinction of ultra-violet rays by the solar atmosphere at about the same limit which the absorptive properties of the Earth's atmosphere place upon the spectra of extra-telluric sources. Theoretically, we might get an image of the Sun without any distinct edge by using only the extreme ultra-violet rays, and there is some advantage in studying them by the aid of an analyzing spectroscope, employing light from the center of the Sun's disk, provided the extra lens is sufficiently transparent to these rays.

The following table is a summary of the coefficients of transmission for the solar atmosphere, as calculated by the exponential formula, assuming uniform photospheric radiation, and perpetuity of all included rays. It is derived from observations on the points $S_4=0.98\ r$, $S_3=0.95\ r$, $S_2=0.75\ r$, $S_1=0.50\ r$, and the center. The computed coefficients being plotted with the radii from which they are derived as abscissae, the errors of observation have been eliminated by mean curves which are straight lines in every case but one. A slight adjustment has been made

TABLE IV.

Computed Transmissions of Solar Rays by the Solar Atmosphere, Neglecting the Influence of Structure.

| $\lambda=$ | 0.416 $\mu$ | 0.468 $\mu$ | 0.550 $\mu$ | 0.615 $\mu$ | 0.781 $\mu$ | 1.01 $\mu$ | 1.50 $\mu$ |
|---|---|---|---|---|---|---|---|
| Deviation | 50′ | 49° | 48° | 47° 30′ | 46° 45′ | 46° 12′ | 45° 28′ |
| 0.98 $r$ | 0.735 | 0.790 | 0.820 | 0.855 | 0.890 | 0.903 | 0.942 |
| 0.95 $r$ | 0.714 | 0.772 | 0.809 | 0.840 | 0.876 | 0.891 | 0.931 |
| 0.75 $r$ | 0.525 | 0.665 | 0.710 | 0.750 | 0.788 | 0.820 | 0.871 |
| 0.50 $r$ | 0.380 | 0.530 | 0.588 | 0.634 | 0.675 | 0.729 | 0.794 |
| Central | 0.200 | 0.258 | 0.345 | 0.400 | 0.450 | 0.540 | 0.638 |

for the series at deviation 46° 12′, but not beyond the limits of error of the observations. The last line gives the concluded vertical or central transmission.

The following final coefficients of transmission have been taken from a smooth curve through the positions obtained from the intersections of the secondary curves with the axis ($S_0 = 0$). The curves of apparent transmission of homogeneous radiations between wave-lengths of 0.3$\mu$ and 2.6$\mu$, deduced in the foregoing manner for different points of the solar disk, and exhibiting to the eye the numerical relations in Tables IV and V, are shown in Plate IV.

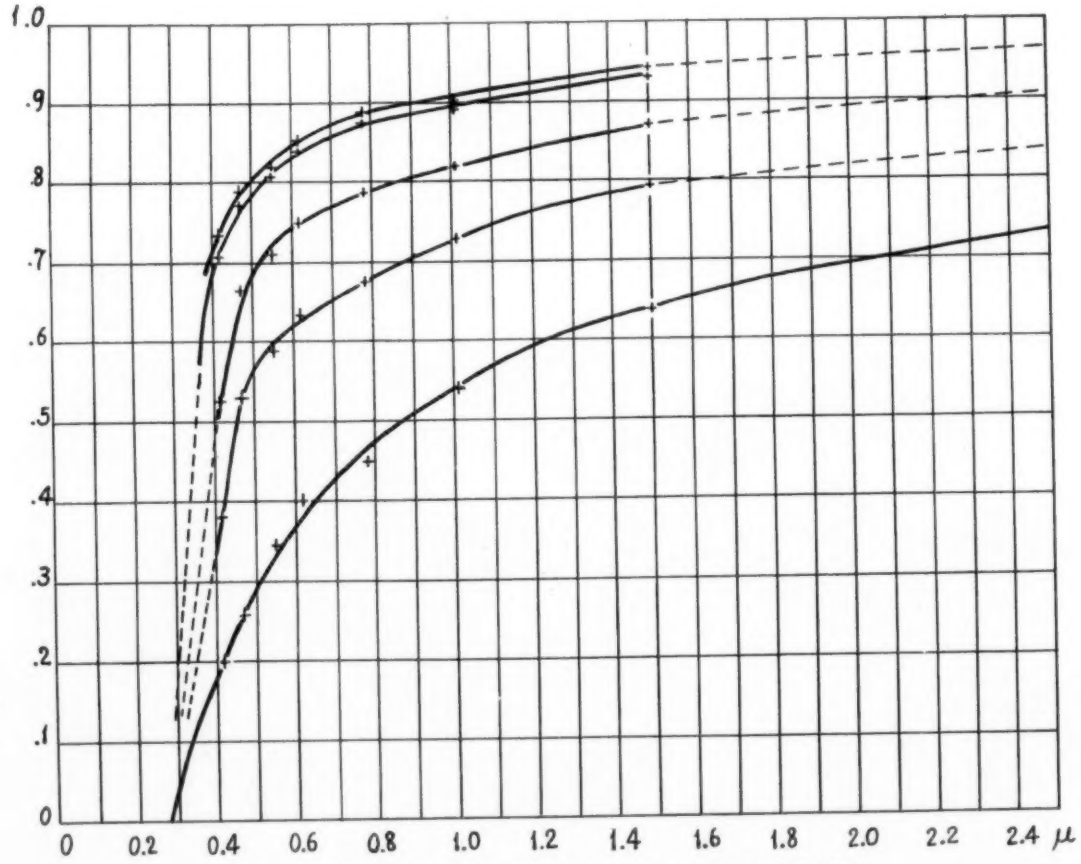
TABLE V.

| Wave-length | 0.30 $\mu$ | 0.40 $\mu$ | 0.50 $\mu$ | 0.60 $\mu$ | 0.70 $\mu$ | 0.80 $\mu$ | 0.90 $\mu$ | 1.00 $\mu$ | 1.50 $\mu$ | 2.00 $\mu$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Transmission..... | 0.05 | 0.18 | 0.29 | 0.37 | 0.43 | 0.475 | 0.51 | 0.54 | 0.64 | 0.69 |

Some indefiniteness attaches to the figures given in Table V on account of the unsatisfactory definition of unit depth of the solar atmosphere. The values specified in this table relate to a mean depth for central regions where this depth is exceptionally great, because here we see down into the interior of the corrugated photosphere. The gases in the depressions are denser, and the equivalent atmospheric mass is greater than it is near the limb where the bottoms of the depressions are invisible. In any case the depth cannot increase as rapidly as the secant of the angle between the radius and the line of sight.

By comparison of these figures with those previously given, assuming an atmosphere of radial depth, it will be seen that the agreement between the results by the two methods is close. Since the various causes of deviation which have been suggested, all conspire to produce similar effects, it does not seem possible to discriminate further between them by mathematical treatment of the data. We have seen, however, that, while there can be no doubt that the principal cause of the depletion of the photospheric radiation is a selective diffuse scattering of the shorter ether-waves by particles of an excessive minuteness, constituting

PLATE IV.




Apparent Transmission Throughout the Spectrum for Each Radius.

an essential, if not the principal ingredient of the inner corona, there is good reason for rejecting the hypothesis of an atmosphere, or dust envelope, of great depth, at least as an efficient modifier of solar radiation; that the greater continuity and increased brilliancy of the naked photosphere at the Sun's limb is sufficient to account for a large part of the peculiarities, with possibly a small contribution from the columnar chromospheric structure; and that the successive extinction of special rays is a further concomitant in the violet and ultra-violet parts of the spectrum.

Assuming equal instrumental efficiency in other respects, the employment of an analyzing, in place of an integrating spectroscope, may be expected to increase the ultra-violet rays between 40 and 50 per cent., the violet rays about 36 per cent., blue rays 30 per cent., citron 22 per cent., and crimson light 14 per cent.

If any variation in the absolute radiation of the Sun is ever certainly detected, it may possibly be found to be associated with some change in the quality or depth of the solar atmosphere, which can best be determined by spectro-bolometric measurements. Whatever change there may be in the solar atmospheric absorption, progressing or fluctuating with the time, it is a quantity of a very small order; yet it seems possible that such an effect may be discriminated by the summation of extensive series of measures similar to the foregoing, but made at maximum and minimum Sun-spot epochs.

As the larger fields of fact become exploited, we must strive for more minute detail. The work outlined here requires persistent systematic cultivation for a long time, such as can scarcely be obtained by the desultory efforts of individuals unable to command their time from year to year. It can be accomplished best at our larger observatories, where it can be made a matter of routine.

# SOME RESULTS OF THE TOTAL ECLIPSE IN SUMATRA, OF MAY 18, 1901, OBTAINED WITH THE PHOTOHELIOGRAPH, AT FORT DE KOCK.

By G. H. PETERS.

ONE of the three parties comprising the United States Naval Observatory eclipse expedition to the island of Sumatra was located at Fort de Kock. This village was about ten miles inside the northern edge of the path of the Moon's shadow, which had a width in that longitude of about 150 miles. The duration of total phase was 176 seconds, while on the central line it was 386 seconds.

The long duration of totality, even close to the limit of the shadow, rendered practical the establishment, near the edge of this path, of a large instrument to photograph the solar surroundings close to the photosphere. Successful spectroscopic work had already been done in similar positions in former eclipses; but no attempt had been made to secure photographs of the region close to the solar limb, with an instrument of this description, and from a like location.

Two instruments were in operation at this station, for recording photographically the eclipse phenomena: a large grating spectrograph, in charge of Dr. W. J. Humphreys, of the University of Virginia, an associate member of the expedition, and a 39-foot photoheliograph of 5 inches aperture, in charge of the writer; the entire station being under the control of Professor W. S. Eichelberger, U. S. N. These instruments were both used horizontally, taking their light from 10-inch silvered glass plane mirrors, at the extremities of the polar axis of a new Brashear coelostat.

The prime object in locating the photoheliograph here was to obtain large scale records of the solar surroundings close to the northern limb. These would show the chromosphere and prominences well uncovered, and at the same time photograph the coro-

nal rays at their departure from the Sun, close to their origin. It was also decided to give longer exposures on more rapid plates, near mid-totality, in order to obtain a record of coronal extension.

Notwithstanding some instrumental difficulties with which we had to contend, the results secured were extremely satisfactory. Moreover the station at Fort de Kock was the only one on the island where absolutely clear weather prevailed during totality. At the other stations the observers were unfortunate in having the sky more or less obscured by haze or thin clouds. The elevation of 3000 feet at this point also added to the atmospheric transparency, while with the Sun just past the meridian, and at a zenith distance of less than 30°, the best astronomical conditions prevailed.

There was, however, one exception to these most favorable conditions. It was found that the "seeing" at Fort de Kock was very unsteady both by day and at night on this and nearly all other occasions when the sky was clear. From our observations while on the island this seems to be a general feature of the climate. The close proximity of two high mountain peaks, to the south of the site selected, one an active volcano, each mountain rising to an altitude of 6000 feet above the table-land on which we were located, probably increased these unfavorable conditions. This poor seeing incident to the climate undoubtedly interfered considerably with the sharp definition of the eclipse photographs.

In all, ten photographs of the eclipsed Sun were obtained with the photoheliograph during totality, and the conditions and results are summarized in the following schedule.

The plates used were Seed's "Gilt Edge," 23 and 27, with a non-halation backing.

The purposes of plates 1 and 9 were to secure records of as much of the projecting chromosphere and prominences as possible, and at the same time impressions of the polar rays. It is to these regions, on the northern limb of the Sun, that special attention is invited.[1]

[1] The Editors regret that it has been impossible to obtain a satisfactory engraving of the plate sent by the author.

| No. | Sensitometer of plate | Length of exposure seconds | Approximate period of count. From | To | Results and Remarks |
|---|---|---|---|---|---|
| 1 | 23 | ½ | ½ | 1 | Shows prominences and chromosphere on northeast limb, and faint coronal rays both polar and equatorial, and coronal disturbance. |
| 2 | 23 | 1 | 9 | 10 | Shows prominences and chromosphere on northeast limb. Stronger coronal and polar rays than No. 1. Polar rays emerging from chromosphere. |
| 3 | 23 | 2 | 18 | 20 | Shows prominences and small amount of chromosphere in northeast limb, together with considerable corona. Some clock rate is perceptible and development was checked in consequence. |
| 4 | 27 | 5 | 28 | 33 | A fine photograph of inner corona, showing coronal disturbance well in outer parts, besides the coronal loops, or arches, also prominences faintly. |
| 5 | 27 | 60 | 43 | 103 | Shows coronal streamers extending, faintly, to the edge of the plate, clock rate fairly good. Some effect of atmospheric unsteadiness noted. |
| 6 | 27 | 20 | 113 | 133 | Considerable clock irregularity, owing to bent worm screw of coelostat. Image considerably blurred. Developing not carried very far in consequence. |
| 7 | 27 | 3 | 141 | 144 | A fine photograph. Shows chromosphere on the northwest limb, prominences and inner corona, together with coronal disturbance and arches. |
| 8 | 23 | 1 | 152 | 153 | Some clock motion. Shows extensive chromosphere on northwest limb; polar rays emerging from chromosphere, corona faint. |
| 9 | 23 | ½ | 161 | 161½ | Comparable with No. 2, but showing slightly less extent of corona. The Moon's limb has here covered the bases of the features on the northeast edge. |
| 10 | 23 | ½ | 176 | 176½ | Taken immediately after third contact, shows a small ray of direct sunlight, giving position of contact, and but little of the corona. |

The chromospheric crescent on these plates is not quite even in surface outline, but is broken up into *billow-like* ridges, resembling, to some extent, the rough limb of the Moon. Some of these *billows* are slightly larger than others, but all have the same general form, and are quite evenly distributed. Wherever they appear, the coronal rays seem to emanate from them. This is especially noticeable with respect to the polar rays, whose

well-defined outlines enable the latter to be traced more clearly to their source. On the original negatives, 2 and 9, these polar rays extend to a distance of 6mm above the atmosphere, the Moon's diameter being 117mm. Some of the polar rays do not coincide very well with these elevations of the chromosphere. In this case it is likely they originate, either in front of or behind the chromospheric limb, and apparently emerge from it only by projection.

The larger irregularities, or prominences, seem to interrupt the flow of coronal matter, which, in several instances, arches over them, forming hoods or envelopes, often with a dark arch between. From a study of these negatives it seems likely that when there is an upheaval of the chromosphere into billows, or in the process of prominence formation, matter in a finely divided or nebulous state is projected outward from their crests. When the eruption has reached a certain development, which is, perhaps, the limit of progressive activity, coronal matter from this part ceases to be given off, or is greatly diminished. This is often the case at the prominences where the coronal matter arches over from the chromosphere on either side.

Another important feature shown on these negatives is in connection with a double prominence at position angle 19°, where a coronal ray apparently emerges from behind a dark arch. This prominence is surmounted by a well-defined arch, which is manifestly composed of less luminous matter than the corona in its immediate vicinity. It is evidently not due to the scarcity of coronal matter. One of the rays composing the great wing in the northeast quadrant apparently emerges from behind this dark arch, extending throughout its whole southern side, and nearly to its top, while the arch maintains its dark appearance uniformly throughout its entire extent.

The corona on the western side of the Sun presents no unusual features, especially in its inner parts. Its structure corresponds, essentially, to that of the preceding year. On the eastern side, however, numerous and remarkable forms are exhibited, thus making a contrast between the two sides which is quite con-

spicuous. Briefly, these features consist of a great wing in the northeast quadrant, composed of a number of well-defined streamers, several of which are in closely associated pairs, extending over a series of medium-sized prominences. Another remarkable object is a coronal disturbance, near the solar equator, apparently the seat of a violent disruptive force, the coronal details resembling, to some extent, the structure seen in photographs of the *Orion* nebula. Attention is also attracted by a series of coronal arches, in the southeast quadrant, separated by darker concentric spaces.

While the north polar rays are apparently symmetrical with respect to the pole of rotation, those at the south pole are excentrically located, the displacement amounting to about 8° toward the east. At this latter point the rays are, moreover, projected directly away from the Sun. Considering the greater coronal activity on the eastern side of the Sun than on the western, this displacement is a striking coincidence.

These and other interesting features of the corona will be treated more at length in the official report, shortly to be issued in the publications of the United States Naval Observatory.

U. S. NAVAL OBSERVATORY,
June 14, 1902.

# NOTE ON THE CONCAVE GRATING.

By H. C. PLUMMER.

IN the case of a grating ruled with equal spaces on any concave surface the simple theory gives the familiar formula

$$N\lambda = \sigma (\sin \phi - \sin \psi),$$

where $\phi$ and $\psi$ are the angles, measured in opposite directions, between the normal at the center of the grating and the directions of the source of light and the focus, $\lambda$ is the wave-length, $N$ the order of the spectrum, and $\sigma$ the grating space.

There must always, however, be a certain amount of aberration, and this is most easily estimated by calculating the retardation of the light diffracted at the extreme line of the grating as compared with that diffracted at the center. For the spherical grating this has been done by Glazebrook (1) in the case where the spaces are equal along the arc;[1] (2) in the case where the spaces are equal along the chord.[2] The former investigation is interesting as showing a disadvantageous way of ruling a grating. The latter shows that the retardation depends on the fourth power of the width of the grating.

The same method can be applied without difficulty and with the same degree of approximation to a grating ruled on any surface. As this does not seem to have been done, and the results in regard to the general degree of approximation appear to be not without interest, the investigation is now given.

The discussion is confined to the plane perpendicular to the lines of the grating. The curve of the grating, referred to the normal and tangent at the center as axes, may be represented by

$$x = ay^2 + by^3 + cy^4,$$

higher powers of $y$ being beyond the degree of approximation contemplated. Let the co-ordinates of $Q$, the source of light, be $u \cos \phi$, $u \sin \phi$, and of $Q_1$, the focus, be $u' \cos \psi$, $-u' \sin \psi$.

[1] *Phil. Mag.*, **15**, 414, 1883. [2] *Phil. Mag.*, **16**, 377, 1883.

Also let $(x, y)$ be the point $P$ on the extreme line of the grating. Then

$$PQ = \{(u\cos\phi - x)^2 + (u\sin\phi - y)^2\}^{\frac{1}{2}}$$

$$= \{u^2 - 2uy\sin\phi - 2ux\cos\phi + y^2 + x^2\}^{\frac{1}{2}}$$

$$= \{u^2 - 2uy\sin\phi + y^2(1 - 2ua\cos\phi) - 2ub\cos\phi \cdot y^3 + (a^2 - 2uc\cos\phi)y^4\}^{\frac{1}{2}}$$

$$= u - y\sin\phi + y\frac{2}{2u}(1 - 2ua\cos\phi) - b\cos\phi \cdot y^3 + \frac{1}{2u}(a^2 - 2uc\cos\phi)y^4 - \frac{1}{8u^3}\{4u^2y^2\sin^2\phi - 4u\sin\phi(1 - 2ua\cos\phi)y^3 + [(1 - 2ua\cos\phi)^2 + 8u^2b\sin\phi\cos\phi]y^4\} + \frac{1}{16u^5}\{-8u^3y^3\sin^3\phi + 12u^2\sin^2\phi(1 - 2ua\cos\phi)y^4\} - \frac{5}{8u^3}y^4\sin^4\phi .$$

Herein powers of $y$ above the fourth have been consistently suppressed. The result, by collecting the several terms, may be written:

$$PQ = u - y\sin\phi + y^2\cos\phi\left(\frac{\cos\phi}{2u} - a\right) + y^3\cos\Phi\left\{\frac{\sin\phi}{u}\left(\frac{\cos\phi}{2u} - a\right) - b\right\} + y^4\left\{\frac{a^2}{2u} - c\cos\phi - \frac{b}{u}\sin\phi\cos\phi - \frac{\cos\phi}{4u^2}\left(\frac{\cos\phi}{2u} - a\right)\left(1 - 2ua\cos\phi - 5\sin^2\phi\right)\right\} .$$

The corresponding expression for $PQ_1$ is obtained at once by substituting $u'$ for $u$ and $-\psi$ for $\psi$ in the preceding expression.

Hence it is seen that if the fourth power of the width of the grating be neglected,

$$PQ + PQ_1 = u + u' - nN\lambda$$

and

$$nN\lambda = y(\sin\phi - \sin\psi),$$

when

$$\frac{\cos\phi}{2u} = a, \quad \frac{\cos\psi}{2u'} = a \quad \text{and} \quad b = 0.$$

Now, if $\rho$ is the radius of curvature of the grating at the origin, $a = \frac{1}{2\rho}$, so that these conditions may be written

$$u = \rho\cos\phi, \quad u' = \rho\cos\psi \quad \text{and} \quad b = 0 .$$

The first two are of course satisfied in Rowland's arrangement, in which the source and spectrum are on the circle described on the radius of curvature. The third condition merely implies that the curve of the grating is symmetrical with respect to the axis.

The term neglected in $PQ+PQ_1$ is now considerably simplified by these conditions, and can now be written

$$\begin{aligned}\delta &= y^4\left(\frac{a^2}{2u} - c\cos\phi + \frac{a^2}{2u'} - c\cos\psi\right)\\ &= y^4\left\{\frac{a^2}{2}\left(\frac{1}{u}+\frac{1}{u'}\right) - 2ac\,(u+u')\right\}\\ &= y^4\left\{a^3(\sec\phi+\sec\psi) - c(\cos\phi+\cos\psi)\right\}.\end{aligned}$$

As an example, let the grating be ruled on a spherical surface of radius $R$. The equation of the grating curve is

$$\begin{aligned}x &= R - (R^2-y^2)^{\frac{1}{2}}\\ &= \frac{y^2}{2R} + \frac{y^4}{8R^3},\end{aligned}$$

so that

$$a = \frac{1}{2R}, \quad c = \frac{1}{8R^3}.$$

Hence

$$\begin{aligned}\delta &= \frac{y^4}{8R^3}\left\{(\sec\phi+\sec\psi) - (\cos\phi+\cos\psi)\right\}\\ &= \frac{y^4}{8R^3}(\sin\phi\tan\phi + \sin\psi\tan\psi),\end{aligned}$$

which is equivalent to the expression given by Glazebrook.

As a second example, let the curve of the grating be parabolic. In this case $c=0$, and it follows immediately that

$$\delta = \frac{y^4}{8R^3}(\sec\phi+\sec\psi),$$

where $R$ is the radius of curvature. It appears therefore that a parabolic surface would be inferior to a spherical surface.

UNIVERSITY OBSERVATORY, OXFORD,
July 4, 1902

# WAVE-LENGTHS OF CERTAIN LINES OF THE SECOND SPECTRUM OF HYDROGEN.

By EDWIN B. FROST.

THE attachment for producing the comparison spectrum in the Bruce spectrograph permits the use of a small vacuum tube when desired, in addition to the spark between metallic terminals. Tubes of a special shape were ordered from F. Müller, successor to Gressler, of Bonn, to be filled with helium.

The tube first tested showed the principal lines of helium, and, on longer exposure, a number of other lines, which proved to be those of the so-called "compound" line or second spectrum of hydrogen. These lines were fine and well suited for service as comparison lines, provided their wave-lengths were known with sufficient accuracy. This, however, is not the case: Hasselberg's wave-lengths were determined before Rowland's work had begun, and when standard lines were lacking; and Ames' later determinations of wave-lengths in the spectrum of hydrogen include but very few of the lines of the second spectrum.

I accordingly took last year a few plates of this spectrum, with comparison spectra of titanium and iron, and have thought it might be of service to others if the wave-lengths measured in the range of spectrum covered by the shorter camera (A) of the Bruce spectrograph were published.

The focal length of the camera is 456 mm, and the dispersion of the three prisms is such that at the wave-length of minimum deviation, $\lambda = 4481$, 1 mm = 13.21 tenth meters (Jena prisms); or, with the Mantois prisms first used, 1 mm = 13.86 tenth-meters. The tube in question was last autumn in such a condition as to bring out the principal lines clearly with an exposure of 60 seconds. Unfortunately it is now extinct, and as none of the other helium tubes have yielded this spectrum, we can at present obtain no new plates. It would have been desirable to obtain

some plates with camera B, of 607 mm focus, which gives sharper definition at the center of the field than does camera A. I have measured four plates: A 84 and 85, taken with the Mantois prisms, and A 210 and 267, taken with the Jena prisms. At my request Mr. Adams was kind enough to measure independently plate A 210.

The measurements were made with three different comparators, using different threads in different cases, and with the plate under the microscope in the position of violet toward left in some instances and violet toward right in others. The reductions to wave-length were made by Hartmann's simple formula (without exponent), and depend upon the wave-lengths of the titanium lines as given in Rowland's solar spectrum tables. The fit of the formula is checked and corrected at numerous points by the comparison lines measured.

The data as to the plates are as follows; Titanium lines measured and used in the reductions: on A 210, by Frost, 30, by Adams, 28; on A 84, 20; on A 85, 8; on A 267, 19. The three helium lines at λλ 4388, 4471 and 4713 were also measured and used in the reductions. On A 210 Adams also employed 7 iron lines in the reductions. The number of formulæ used on each plate, each covering a small section of the spectrum, were: A 210 by Frost, 3; by Adams, 2; A 84, 3; A 85, 1; A 267, 2 formulæ.

A 210 was measured in each case with violet to right, and with a single thread; A 84 with violet to left, and with a double thread; A 85 with violet to right and single thread; A 267 with violet to left and double thread. The double thread doubtless largely eliminates the physiological effect, which should here be small in any event, as all the lines are emission lines and dark on the negative. If these plates had originally been taken and measured with a view to the most precise determinations of wave-length possible with the instruments used, a more uniform procedure would have been followed; but in view of the variety of conditions described above, the mean of the different results should probably be fairly freed from individual peculiarities of the

different plates. Four settings were regularly made on each line, but on A 85, for which the exposure was such as to make the stronger lines very sharp, only two settings were ordinarily made on the hydrogen lines.

Although the measures from the different plates are doubtless entitled to different weights, the assignment of weights would be quite arbitrary, and I accordingly give the simple mean from the five measures of four plates. This gives to plate A 210 a double weight, which is proper, as it is the best spectrum for measurement, although not yielding nearly as many lines as the longer exposed plate A 84.

The intensities of the lines were roughly estimated when the settings were made, on a scale in which a fairly distinct line is recorded as 10 and the very faintest lines visible as 2 or 3. Inasmuch as the different plates were of very different degrees of strength these estimated intensities have very different absolute values for the different plates. Moreover A 84 and A 267 were only recently measured, a year later than the other two plates, so that the scale would presumably change greatly. The estimates on A 84 would be the nearest to the truth, as this plate includes many faint lines invisible on the other plates.

In the following table *d* denotes double, *n* denotes nebulous; *cv* signifies that there is a *comes* on the violet side, either too close or too faint for measurement; *cr* that there is a *comes* on the side toward the red end of the spectrum.

A comparison of these results with those of other observers is not given above, as Ames in his paper on the hydrogen spectrum (*Phil. Mag.*, **30**, 33, 1890) measured only 9 lines in the range of spectrum included above. For the 5 lines whose wavelengths are given by Ames to the hundredth of the tenth-meter, the differences F.—A. are as follows: λ 4412.47, +0.12; 4447.77, −0.08; 4498.69, −0.06; 4634.21, +0.06; 4683.97, +0.22.

Hasselberg's values[1] depend on Ångström's scale, hence are

[1] *Bull. Acad. Imp.* St. Petersburg, **11**, 307, 1880; **12**, 203, 1884; *Mem. Acad. Imp.* St. Petersburg, **30**, 1882; **31**, 1883. I have not had access to these papers, but have only examined his values as given in the "Index of Spectra" of Watts.

WAVE-LENGTHS OF LINES IN THE "SECOND SPECTRUM" OF HYDROGEN.

| A 210 (F.) | | A 210 (A.) | A 84 | | A 85 | | A 267 | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| 4358.51 | 8 | 4358.52 | 4358.51 | 15 | | | | | 4358.51 |
| | | | 4386.41 | 5 | | | | | 4386.4 |
| 4391.14 | 6 | 4391.15 | 4391.09 | 4 | | | | | 4391.13 |
| | | | 4391.90 | 3 | | | | | 4391.9 |
| | | | 4393.02 | 5 | | | | | 4393.0 |
| | | | 4398.28 | 2 | | | | | 4398.3 |
| | | | 4400.94 | 2 | | | | | 4400.9 |
| | | | 4401.79 | 2 | | | | | 4401.8 |
| 4412.48 | 12 | 4412.50 | 4412.44 | 15 | 4412.45 | 12 | 4412.47 | 8 | 4412.47 |
| 4413.70 | 3 | 4413.75 | 4413.65 | 2 | | | | | 4413.70 |
| 4414.43 | 5 | 4414.49 | 4414.38 | 6 | 4414.48*cr* | 6 | 4414.38 | 3 | 4414.43 |
| | | | 4415.16 | 4 | | | 4415.16 | 1 | 4415.16 |
| | | | 4416.43 | 2 | | | | | 4416.4 |
| 4417.49 | 8 | 4417.48*d i* | 4417.49 | 12 | 4417.51 | 8 | 4417.50 | 7 | 4417.49 |
| | | | 4422.86 | 3 | | | | | 4422.9 |
| | | | 4423.43 | 2 | | | | | 4423.4 |
| | | | 4426.13 | 5 | | | | | 4426.1 |
| 4437.77 | 6 | | | | | | | | 4437.8 |
| | | | 4445.44 | 7 | | | | | 4445.4 |
| 4447.83*nr* | 7 | 4447.80*d* | 4447.74*d* | 15 | 4447.74 | 7 | 4447.73*cr* | 4 | 4447.77 |
| | | | 4450.11 | 3 | | | | | 4450.1 |
| | | | 4453.22 | 2 | | | | | 4453.2 |
| | | | 4456.91 | 8 | | | | | 4456.9 |
| | | | 4458.97 | 6 | | | | | 4459.0 |
| 4461.17 | 12 | 4461.17 | 4461.14 | 20 | 4461.13 | 15 | 4461.14 | 10 | 4461.15 |
| | | | 4464.19*d* | 3 | | | | | 4464.2 |
| 4467.36 | 4 | 4467.33 | 4467.33 | 6 | | | 4467.31 | 3 | 4467.33 |
| 4474.42 | 4 | 4474.44 | 4474.41 | 8 | | | 4474.43 | 4 | 4474.42 |
| | | | 4477.24 | 3 | | | | | 4477.2 |
| | | | 4482.19 | 3 | | | | | 4482.2 |
| | | | 4486.21*cv* | 8 | | | 4486.21 | 3 | 4486.21 |
| 4488.05 | 7 | 4488.02 | 4488.00 | 12 | 4487.98 | 6 | 4487.98 | 5 | 4488.01 |
| 4490.65 | 9 | 4490.59 | 4490.68 | 15 | 4490.66 | 7 | 4490.63 | 6 | 4490.65 |
| 4493.83 | 2 | | 4493.87 | 8 | | | 4493.83 | 2 | 4493.84 |
| | | | 4495.57 | 2 | | | | | 4495.6 |
| 4498.18 | 3 | 4498.30 | 4498.25 | 12 | 4498.28 | 5 | 4498.48 | 5 | 4498.25 |
| 4498.70 | 5 | 4498.74 | 4498.66 | 12 | 4498.67 | 7 | | 5 | 4498.69 |
| | | | 4502.17*cr* | 6 | | | | | 4502.2 |
| | | | 4503.96 | 6 | | | | | 4504.0 |
| | | | 4505.16 | 5 | | | | | 4505.2 |
| 4505.80 | 5 | 4505.81 | 4505.86*cr* | 7 | 4505.73 | 3 | 4505.78 | 3 | 4505.80 |
| | | | 4507.05 | 7 | | | | | 4507.0 |
| | | | 4509.12 | 4 | | | | | 4509.1 |
| | | | 4510.98 | 12 | | | | | 4511.0 |
| 4514.50 | 3 | 4514.49 | 4514.47 | 5 | | | 4514.44 | 2 | 4514.48 |
| 4515.70 | | | 4515.72 | 2 | | | | | 4515.71 |
| | | | 4520.17 | 5 | | | | | 4520.2 |
| | | | 4521.62 | 3 | | | | | 4521.6 |
| | | 4524.27 | 4527.36 | 12 | | | 4524.23 | 4 | 4524.29 |
| | | | 4529.37 | 4 | | | | | 4529.4 |
| | | | 4532.18 | 2 | | | | | 4532.2 |
| | | | 4533.30 | 4 | | | | | 4533.3 |

WAVE-LENGTHS OF LINES IN THE "SECOND SPECTRUM" OF HYDROGEN (*continued*).

| A 210 F | | A 210 A | A 84 | | A 45 | | A 267 | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | | | 4534.61*nd* | 10 10 | | | | | 4534.6 |
| 4538.42 | 4 | 4538.42 | 4538.46 | 10 | 4538.49 | 4 | 4538.36 | 2 | 4538.43 |
| | | | 4539.34 | 3 | | | 4539.26 | 2 | 4539.30 |
| 4543.92 | 3 | 4543.92 | 4543.90 | 12 | 4543.87 | 2 | 4543.86 | 3 | 4543.89 |
| | | | 4550.31 | 3 | | | | | 4550.3 |
| 4551.15 | 6 | 4551.11 | 4551.14 | 18 | 4551.16 | 15 | 4551.18 | 6 | 4551.15 |
| | | | 4554.32 | 7 | | | 4554.25 | 2 | 4554.28 |
| | | | 4557.46 | 3 | | | | | 4557.46 |
| | | | 4558.79*n* | 15 | 4558.78*d?* | | 4558.67*dn* | | 4558.75 |
| | | | 4562.45 | 3 | | | | | 4562.4 |
| | | | 4563.94 | 8 | 4563.97 | 3 | | | 4563.96 |
| 4568.38 | 13 | 4568.33 | 4568.37 | 25 | 4568.37 | 18 | 4568.28 | 10 | 4568.35 |
| 4572.93 | 15 | 4573.02 | 4572.96 | 35 | 4572.91 | 16 | 4572.87 | 8 | 4572.94 |
| 4576.09*n* | 4 | 4576.12 | 4576.11 | 10 | 4576.08 | 8 | 4576.02 | 3 | 4576.08 |
| 4578.20 | 5 | 4578.30 | 4578.27 | 12 | 4578.19 | 6 | 4578.14 | 4 | 4578.22 |
| 4579.65 | 2 | 4579.76 | | | | | | | 4579.70 |
| 4580.20 | 15 | 4580.28 | 4580.24*cv* | 20 | 4580.16 | 20 | 4580.15 | 12 | 4580.21 |
| 4581.77 | 6 | 4581.78 | 4581.74 | 9 | 4581.74 | 7 | 4581.71 | 3 | 4581.75 |
| 4582.81 | 8 | 4582.81 | 4582.80 | | 4582.76 | 12 | 4582.74 | 7 | 4582.78 |
| | | | 4598.73 | 6 | | | | | 4598.7 |
| 4607.57 | 6 | 4607.58 | 4607.65 | 12 | 4607.61 | 4 | 4607.51 | 3 | 4607.58 |
| 4618.48 | 5 | 4618.46 | 4618.52 | 15 | 4618.47 | 5 | 4618.41 | 6 | 4618.47 |
| 4625.53*n* | 7 | 4625.58 | 4625.54 | 15 | 4625.55*n* | 6 | 4625.47 | 4 | 4625.53 |
| 4628.19 | 9 | 4628.15 | 4628.17 | 20 | 4628.22 | 12 | 4628.12 | 10 | 4628.17 |
| 4632.01*nv* | 13 | 4632.10*cv* | 4631.97 | 80 | 4632.09*d* | 15 | 4631.91*n* | 20 | 4632.02 |
| 4634.16 | 15 | 4634.23 | 4634.21 | 50 | 4634.24*d* | 15 | 4634.19*cr* | 15 | 4634.21 |
| 4634.78 | 8 | 4634.79 | 4634.74 | 20 | | | | | 4634.77 |
| | | | 4645.51 | 4 | | | | | 4645.5 |
| | | 4653.07 | 4653.23 | 12 | 4653.25 | 4 | 4653.16 | 3 | 4653.18 |
| | | | 4660.57 | 3 | | | | | 4660.6 |
| | | | 4661.63 | 5 | 4661.66 | 2 | | | 4661.64 |
| 4662.97 | 8 | 4662.92 | 4663.01 | 15 | 4662.92 | 8 | 4662.92 | 2 | 4662.95 |
| | | | 4671.47 | 5 | | | | | 4671.5 |
| | | | 4679.29 | 2 | | | | | 4679.3 |
| 4683.96 | 7 | 4683.92 | 4683.95 | 12 | 4684.06 | | | | 4683.97 |
| | | | 4690.29 | 8 | | | | | 4690.3 |
| 4719.17 | 12 | 4719.1 | 4719.09 | 8 | 4719.1 | | 4719.1 | | 4719.11 |
| 4723.13 | 15 | 4723.1 | 4725.15 | 15 | 4723.2 | | 4723.2 | | 4723.16 |

Additional lines, seen but not measured: Plate A 84. Six pairs of faint lines precede λ4386; 2 lines between λ4388 and λ4391; faint pair between λ4417 and λ4422; faint pair near λ4437.

not directly comparable; but after applying systematic corrections to his scale, 70 of the 90 lines given above can be certainly identified with 70 of the 107 lines he measured (to tenths of a tenth-meter) in this region. The difference between our values

is in most cases not over 0.3 tenth-meters, and only occasionally rises as high as 0.6 tenth-meters.

Of course no guaranty can be given that the lines yielded by our helium tube are all to be assigned to the second spectrum of hydrogen, but the comparison with the results of Hasselberg indicates that at least the great majority were due to the same substance in the two cases.

It seems singular that this spectrum should not be more in evidence in celestial spectra. There are a few possible coincidences with lines of the chromospheric spectrum, and with lines in spectra of temporary stars. Of the five principal coronal lines, at λλ 3987, 4231, 4359, 4568, and 5303, all but the second fall near to the positions of lines observed in the second spectrum of hydrogen, but at present it cannot be asserted that this is more that an accidental coincidence.

YERKES OBSERVATORY,
August 21, 1902.

# OBSERVATIONS ON THE MAGNETIC ROTATION OF THE PLANE OF POLARIZATION IN THE INTERIOR OF AN ABSORPTION BAND.[1]

By P. ZEEMAN.

1. THE difficulties of a complete theory of emission are partly avoided in a treatment beginning with the absorption, and this may have been the reason why Voigt[2] has followed this procedure, though it must be granted that in his method an explanation of the mechanism of the phenomena as in Lorentz's theory cannot be given.[3] In Voigt's theory the separation of a spectral line by the action of a magnetic field is found as the separation of an absorption line.

Some particulars in this separation were anticipated by this theory[4] and confirmed by experiment.[5]

The long known phenomenon of the rotation of the plane of polarization and the magnetic separation of the spectral lines were closely connected.[6]

One result, however, of Voigt's[7] theory relating to the rotation of the plane of polarization in the interior of an absorption band seemed to be in contradiction with the results of Corbino[8] or at least were not confirmed by the experiments of Schmauss.[9]

[1] From the Proceedings of the Royal Academy of Sciences of Amsterdam, meeting of Saturday, May 31, 1902.

[2] *Wied. Ann.*, **67**, 345, 1899.

[3] For a comparison of the advantages of the theories of Lorentz and of Voigt, see LORENTZ, Rapports, congrès, Paris, **3**, 16, 33, 1900; *Phys. Zeitschr.*, 1, 39, 1899; *cf.* also PLANCK, *Sitz.ber. Ak. Berlin*, p. 470, 1902.

[4] VOIGT, *Annalen der Physik*, 1, 376, 1900.

[5] ZEEMAN, *Versl. Akad. Amsterdam*, December, 1899; *Archiv. Néerl.* (2), **5**, 237.

[6] *Cf.* also LARMOR, "Æther and Matter," p. 203.

[7] *Ann. der Physik*, (4), **6**, 784, 1901.

[8] *Atti R. Acc. dei Lincei.* **10**, 137, 1901; *Nuovo Cimento*, February, 1902.

[9] *Ann. der Physik*, **2**, 280, 1900.

The theory of Voigt requires a negative [1] rotation of the plane of polarization in the interior of an absorption band; Corbino, however, only succeeded in observing a very small positive rotation.

It would be very remarkable, however, if there existed a disagreement between theory and observation in this special field so closely connected with other well-understood phenomena.

I have been experimenting for some time on this subject. In performing these experiments I have been aided in an excellent manner by Mr. Hallo.

I have succeeded in observing a negative rotation in the interior of an absorption band, the results of my observations being in perfect *qualitative* agreement with Voigt's theory.

2. The method used in the following observations on the rotation in sodium vapor is in principle the same as that which has been used by Voigt [2] in his demonstration of the double refraction of sodium vapor placed in a magnetic field. Hussel [3] had already used it in a determination of the natural rotation of the plane of polarization in quartz, and also Corbino in his first experiments on sodium.

By means of a system of quartz prisms (as has been used by Fresnel in his experiment on the division of a plane-polarized ray into two circularly polarized rays) a number of horizontal interference fringes are formed in a spectrum. The light traverses the prism in the direction of the axis, and the edges are horizontal and perpendicular to the slit of the spectroscope. The prism system (length 50 mm) was placed in my experiments as near as possible before the slit of spectral apparatus and a small Nicol, used as analyzer, behind the slit. The polarizing Nicol was placed, of course, before the electro-magnet (of the Ruhmkorff type). The spectroscope was a Rowland grating, for which I am indebted to the kindness of the directors of the Dutch Society of Sciences at Harlem. It has a radius of 6.5 meters, 10,000 lines to the inch, and a divided surface of nearly 14 cm.

[1] The magnetic rotation in the vicinity of the band is positive in sodium vapor.

[2] *Wied. Ann.*, **67**, 360, 1899. [3] *Wied. Ann.*, **43**, 498, 1891.

The grating was mounted for parallel light in the manner indicated by Runge and Paschen.[1] The source of light was in most cases the electric arc, in some the Sun.

Using this arrangement of the experiment we can deduce immediately from the deformation of the interference fringes in the neighborhood of the absorption bands, when the sodium vapor is under the action of the magnetic field, the value of the rotation of the plane of polarization for different wave-lengths. Fig. 1 of the plate gives an idea of the aspect of the fringes in absence of the field in the neighborhood of the sodium lines, considerable sodium being present in the flame between the poles. The observations were made in the second order.

3. In the experiment first to be described, the distance between the perforated poles was about 4 mm and the intensity of the field about 15,000 c. g. s. units. In this field was placed a gas flame fed with oxygen, and a small quantity of sodium was introduced in it by means of a glass rod. After removal of the polarizer and of the Fresnel prism the two doublets, in which the sodium lines are separated, in the inverse magnetic spectral effect were observed. Between the components of the doublet were seen the very narrow reversed sodium lines due to the arc light itself.

The polarizer and the prism were now introduced in their proper places. The field of view was then crossed by the above-mentioned (2) dark, nearly horizontal interference fringes.

I now wished to ascertain the deformation of the fringes by increasing continuously the quantity of sodium vapor, the field remaining constant. This method must be preferred for obvious reasons to the other which might have been followed also, viz., the examination of a flame with constant percentage of sodium under varying magnetic intensities.

The following observations refer to $D_1$:

If the quantity of sodium in the magnetic field was only extremely small, the interference fringe exhibited at the place of the reversed sodium line a protuberance — let us say *down-*

[1] KAYSER, *Handbuch*, 1, 482.

*ward*—the lines of the doublet being somewhat stronger just above the interference fringe. In Fig. 1 this behavior is represented schematically.

Increasing now the quantity of sodium (always remaining very small, however, absolutely) the interference fringes moved upward along the components of the doublet, whereas the part of the fringe between the components seemed no longer connected to the exterior fringes and assumed the shape figured schematically in Fig. 2.

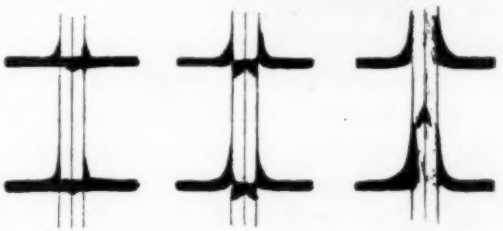


FIG. 1. FIG. 2. FIG. 3.

Increasing still further the density of the vapor the interior part of the fringe slid downward with increasing velocity and then resembled an arrow with point directed upward, the parts more removed from the medium line fading away and disappearing (see the schematic Fig. 3). At last the arrow entirely disappeared by the increase of the density of the vapor. It then became impossible to distinguish the fringes or any trace of structure in the field between the components. Considerable light was transmitted. The entire width of the components of the doublet was now about of the same order as the distance of their central lines.

A further increase of the quantity of sodium obscured the central part more and more (see below (8)).

The exterior fringes moved continuously upward while the density was being increased.

In a field of about 20,000 units the downward displacement could be followed over a distance of more than the double of the distance between two fringes, corresponding to a *negative* rotation of over $2 \times 180°$, say 400°. The distance between the poles was 4 mm.

Some more accurate data will be given on another occasion.

In the case of $D_2$ the phenomena were in the main of the same character.

For $D_2$ it was, however, characteristic that the stage of the nearly or entirely vanishing of the interior fringes was reached with smaller field, whereas also the shape of the interior fringe differed from the one observed in the case of $D_1$. Hence there exists also in this case a difference between $D_1$ and $D_2$, a difference already known to exist in the phenomena of reversal, of the separation by a magnetic field, and of the rotation of the plane of polarization in the vicinity of the absorption band.

4. It appeared possible to keep each of the stages described in (3) stationary during a considerable time. Excellent photographs could be secured with plates which were sensitized for yellow light with erythrosine silver. Instead of the gas flame fed with oxygen it was easier, in the case of greater distances between the poles, to use a Bunsen burner wherein common salt was introduced.

5. If the density of the vapor was maintained as constant as possible and if it and the field intensity corresponded to the circumstances represented in Fig. 3 (3) then an *increase* of the field gave a motion of the arrow (Fig. 3) (3) upwards, corresponding to a *decrease* of the negative rotation and reciprocally. It was possible to observe by eye observation very clearly this decrease when the field was changed, *e. g.*, from 18,000 to 25,000. If the circumstances were more in accordance with Fig. 2 (3) then the same change of field produced a change only just perceptible of the negative rotation but in the same sense as mentioned in the case of Fig. 3.

An enlarged reproduction of one of the photographs is shown in Fig. 2 of the plate. The distance between the poles in this experiment was 6.3 mm, the field intensity about 14,000.[1] The negative rotation in the case of $D_1$ is somewhat less than 90°. In the case of $D_2$ only some traces of the interior fringes can yet be seen (3). The negative rotation is about 180°. In the photograph are seen also the reversed very narrow $D_1$ line and

[1] The intensities of the field were measured by means of a bismuth spiral in the center of the field. Probably the values given are somewhat too high. Measurements of the magnetic change of the spectral lines give lower values.

the broader $D_2$ line, which are due to the arc itself and have nothing to do with our subject.

6. The observations (3, 4, 5) agree qualitatively in an excellent manner with the conclusions from Voigt's theory. According to it, the negative rotation must be of the same order of magnitude as the positive one. This last was known from Macaluso's and Corbino's experiments to be very great. The enormous value and the sign of the negative rotation given in (3) may thus be regarded as a beautiful confirmation of the theory.

This is equally the case with the direction (5) of the change of the negative rotation with increasing field. In order to see this we must know the value of the quantity occurring in the theory $P=\frac{cR}{\theta}$ ($R=$ field intensity, $c$ and $\theta$ parameters of the absorption band), for which the comparison must take place. It was possible to assign a value to $P$ by comparison of the phenomenon with Voigt's Fig. 1.[1] This figure gives $n\chi_0$ ($\chi_0$ angle of rotation, $n$ a mean value of the index of refraction) as function of a certain variable $\Delta$, whereas our phenomenon is a represention of $\chi_0$ as a function of $\lambda$. Reducing the abscissa of the mentioned Fig. 1 to $\frac{1}{20}$ or $\frac{1}{25}$, we obtain diagrams resembling in the main features Fig. 2 of the plate. To the greater observed negative rotation (3) correspond values of $P$, which can be estimated at 5 or 8. The smallest easily observed rotations in the strong field used are probably in the vicinity of the critical value $P=1.73$.

7. The slope of the exterior interference fringes is greater toward the side of the greater wave-lengths than toward the violet, at least so far as the rotation due to one band does not influence visibly the rotation due to the other. At the same distances, if not very small, of each of the two D lines the rotation at the side of the violet is greatest. The interior fringes also show a slight asymmetry, so, *e.g.*, the point of the arrow in Fig.

[1] *Annalen der Physik*, **6**, 789, 1901.

3 (3) ought to be asymmetrical. The part at the side of the violet is predominating.

It is clear that these phenomena depend upon an asymmetry of the dispersion curve.

8. With very dense sodium vapor, hence under circumstances which are beyond the last stage of (3), I observed phenomena very probably identical with those observed by Corbino. In my first experiments with those dense vapors I thought it absolutely necessary for securing sufficient intensity to widen the slit beyond the width used in the experiments already given. I now see, however, that this is unnecessary.

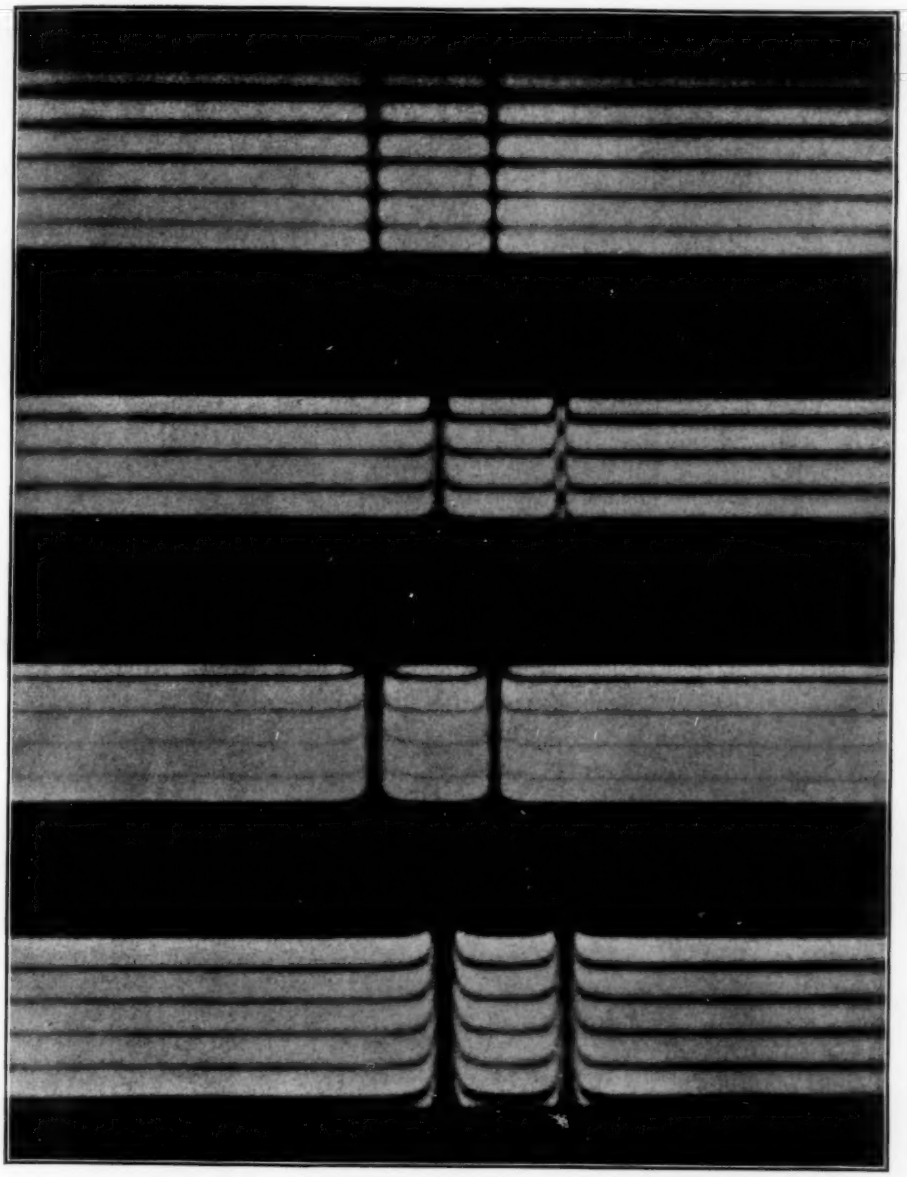
Using these very dense vapors one sees in the absorption band a horizontal part of an interference fringe, which seems to have undergone a very small displacement *upwards* by the action of the field. These horizontal parts are more ill-defined and broader and the whole phenomenon in the bands is darker than under the circumstances described in (3), (4), (5).

Figs. 3 and 4 of the plate will give a clearer impression of the change in the phenomenon than a long description.

Fig. 3 was obtained with a field of 4500 units and much sodium. I have made some measurements, according to a method not to be given here, concerning the displacement of the central (in horizontal and vertical direction) part of the interference fringe, and I have found a displacement which would correspond to a *positive* rotation of about 8° with both D lines. Fig. 4 was taken with a field of 10,700 and much sodium. The exterior interference fringes are very clear and much deformed; the rotation in the parts adjacent to the absorption band exceed 180°. The interior interference fringes are very indistinct. Their appearance would suggest that in the case of $D_1$ in Fig. 4 the stage reached for $D_2$ in Fig. 2 has been scarcely surpassed.

This, however, cannot be the case because there was too much sodium in the flame. A comparison with Fig. 2 will show that the lines are much broader in Fig. 4. Measurements taken on other negatives gave me for fields of 11,000, displacements of about $\frac{1}{16}$ of the distance between two fringes corresponding to a

PLATE V




$D_2$ $D_1$

MAGNETIC ROTATION IN THE INTERIOR OF AN ABSORPTION BAND (P. ZEEMAN).

positive rotation of 11°. Hence the displacements in these cases are precisely of the same order of magnitude as in Corbino's experiments. The paleness of the borders of the band is easily accounted for by the remark that there the intensity of one of the circularly polarized rays largely exceeds the other.

I do not believe that these facts are in contradiction with theory. It is true that it requires for very high values of $P$ a value zero for $(n\chi_0)_1$. If we must take as the locus of the fringe the mean vertical height, then really the rotation would be positive. It seems possible that with those broad fringes the case is different. It is also possible that the circumstances assumed in the theory are not wholly realized in the experiments with dense vapors. I am making some new experiments on this subject and therefore shall not discuss further the different possibilities.

## EXPLANATION OF THE PLATE.

The plate gives about fourfold enlargements of the photographs.

Fig. 1. Interference fringes and absorption lines in absence of the field and with considerable sodium (2).

Fig. 2. Same lines. Field intensity about 14,000, little sodium (3) (5).

Fig. 3. Same lines. Field intensity about 4,500, much sodium (8).

Fig. 4. Same lines. Field intensity about 10,700, much sodium (8).

# *Minor Contributions and Notes.*

## SIX STARS WHOSE VELOCITIES IN THE LINE OF SIGHT ARE VARIABLE.[1]

The following six spectroscopic binaries, discovered with the Mills spectrograph, are additional to the thirty-two binaries already announced:

*φ Persei* ($\alpha = 1^h\ 37^m$; $\delta = +\ 50°\ 11'$).

The variable velocity of this star was discovered from the second plate. The observations are:

| Date | | | Velocity | Measured by |
|---|---|---|---|---|
| 1898 | September | 5 | — 2 km | Reese |
| 1900 | December | 16 | +24 | Reese |
| | | 16 | +23 | Campbell |
| 1901 | October | 15 | —10 | Reese |
| | November | 11 | —12 | Reese |

This star has bright hydrogen lines, its bright $H\beta$ having been discovered by Espin (*Astr. Nach.*, No. 2963). The $H\gamma$ line may perhaps be best described as a comparatively narrow absorption line with very bright borders. The measures refer to the middle of the dark line. No other lines are apparent in the $H\gamma$ region.

*η Geminorum* ($\alpha = 6^h\ 09^m$; $\delta = +\ 22°\ 33'$).

The observations of this star thus far secured are as follows, the variable velocity having been discovered from the third plate:

| Date | | | Velocity | Measured by |
|---|---|---|---|---|
| 1900 | January | 15 | +15.8 km | Reese |
| | | 15 | +14 | Stebbins |
| | January | 21 | +15.0 | Reese |
| 1901 | October | 13 | +22.1 | Reese |
| | November | 6 | +20.3 | Reese |
| | December | 4 | +22.8 | Reese |
| 1902 | February | 2 | +25 | Reese |
| | | 2 | +23 | Stebbins |

*γ Canis Minoris* ($\alpha = 7^h\ 23^m$; $\delta = +\ 9°\ 08'$).

[1] From *Bulletin* No. 20, *Lick Observatory, University of California.*

The observations of this star are:

| Date | | | Velocity | Measured by |
|---|---|---|---|---|
| 1900 | October | 29 | +44 km | Reese |
| | | 29 | +44 | Stebbins |
| 1901 | November | 6 | +41 | Reese |
| | | 6 | +40 | Stebbins |
| | December | 22 | +54 | Reese |
| | | 22 | +53 | Stebbins |
| | December | 30 | +50 | Reese |

The fourth plate is underexposed.

$\xi$ *Herculis* ($\alpha = 16^h\ 38^m$; $\delta = +\ 31^\circ\ 47'$).

Early observations of the radial velocity of this star were obtained by Bélopolsky at Pulkowa, Campbell at Mount Hamilton, and Newall at Cambridge, as follows:

| Date | | | Velocity | Measured by |
|---|---|---|---|---|
| 1893 | May | 18 | —68 km | Bélopolsky |
| | | 22 | —84 | Bélopolsky |
| | June | 2 | —75 | Bélopolsky |
| | | 3 | —67 | Bélopolsky |
| | | 4 | —66 | Bélopolsky |
| | | 14 | —64 | Bélopolsky |
| | | 16 | —69 | Bélopolsky |
| | Mean | | —70.4 | |
| 1897 | April | 29 | —69.1 | Campbell |
| 1898 | May | 11 | —70.4 | Campbell |
| | | 23 | —70.0 | Campbell |
| | August | 19 | —70.9 | Campbell |
| | Mean | | —70.1 | |
| 1897 | June | 14 | —71.4 | Newall |
| 1898 | May | 16 | —68.4 | Newall |
| 1899 | April | 29 | —74.3 | Newall |
| | Mean | | —71.4 | |

The above observations afforded no evidence whatever of variable velocity.

Recent observations at the Lick Observatory are as follows:

| | Date | | Velocity | Measured by |
|---|---|---|---|---|
| 1901 | July | 1 | —74 km | Wright |
| | | 1 | —73.9 | Reese |
| | August | 6 | —75.8 | Reese |
| 1902 | April | 13 | —74.2 | Reese |
| | Mean | | —74.6 | |

The velocity has therefore changed about $4^{km}$ since 1898.

This star is a well-known visual binary, period about thirty-three years.

$\alpha$ *Equulei* ($\alpha = 21^h\ 11^m$; $\delta = +4^\circ\ 50'$).

The variable velocity of this star was detected from the third of the following observations:

| | Date | | Velocity | Measured by |
|---|---|---|---|---|
| 1900 | June | 25 | —26 km | Wright |
| | July | 18 | —22 | Wright |
| 1901 | June | 25 | — 2 | Wright |
| | September | 1 | —14 | Wright |
| | October | 15 | —12 | Reese |
| 1902 | June | 2 | —26 | Stebbins |

This star has a composite spectrum, discovered by Miss Maury, of Harvard College Observatory.

$o$ *Andromedae* ($\alpha = 22^h\ 57^m$; $\delta = +41^\circ\ 47'$).

The following observations of this star have been secured:

| | Date | | Velocicy | Measured by |
|---|---|---|---|---|
| 1900 | October | 9 | —11 km | Wright |
| | December | 17 | —15 | Campbell |
| | | 17 | —17 | Wright |
| 1901 | June | 25 | —20 | Wright |
| | August | 12 | —12 | Reese |

These measures depend entirely upon the excellent $H\gamma$ line.

This star has a composite spectrum, discovered likewise by Miss Maury.

Before the discovery of the thirty-eight spectroscopic binaries with the Mills spectrograph, three had been discovered in the same list of stars by Bélopolsky, making forty-one binaries in about 350 stars observed. The proportion is therefore one binary star for every eight

observed, not taking into account a considerable list of suspected cases awaiting confirmation. The variable velocity of our Sun, due to its revolving planets, has a double amplitude of only a few hundredths of a kilometer. As the work progresses, and the degree of accuracy attainable increases, we shall probably find that there is a regular gradation of double amplitudes from that of the Sun up to those of the spectroscopic binaries already discovered, and it is possible that the star which is not a spectroscopic binary will prove to be the rare exception.

Acknowledgments are due to Messrs. Wright and Reese for continued efficient assistance in the line of sight work.

W. W. CAMPBELL.

July 1, 1902.

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## OBSERVATIONS ON ζ *GEMINORUM.*

FROM March 10 to May 23, 1902, forty-two observations were made by Argelander's method on ζ *Geminorum*. Only a preliminary reduction is here attempted. The following light scale was deduced from the observations and used in the reduction. $\delta = 10.0$, $\lambda = 10.1$, $\iota = 11.7$, $\nu = 13.7$, $\sigma = 14.7$. The observations make it appear probable that a secondary maximum occurs $3^d.0$ before the principal maximum and that it attains the brightness of 3.88 mag. A secondary minimum is also indicated $1^d.6$ before the principal maximum. It has a magnitude of about 3.93. The following observed minima are compared with an ephemeris computed from the elements given in Chandler's *Third Catalogue of Variable Stars*. The minima are given in the Julian Day and G. M. T. The weights are proportional to the number of observations.

| Obs. Min. | Wt. | C.-O. |
|---|---|---|
| 2415823.18 | 2 | + 0.89 |
| 32.89 | 3 | + 1.33 |
| 53.83 | 2 | + 0.70 |
| 63.66 | 2 | + 1.02 |
| 73.81 | 2 | + 1.02 |
| 83.81 | 1 | + 1.18 |

The mean by weights gives a correction to the ephemeris of $+1^d.04 \pm 0^d.06$.

F. P. MCDERMOTT, JR.

PRINCETON UNIVERSITY,
June 1902.

## ON THE RADIATION OF MERCURY IN THE MAGNETIC FIELD.

In the list of mercury lines whose separation in the magnetic field we measured,[1] the lines λλ 3655.00, 3650.31, 3027.66, 3025.79 belonging to the first secondary series were by accident not printed, and we did not notice the omission when reading the proof sheets. We ask permission herewith to supplement the omitted measurements:

| Wave-lengths | Oscillations parallel to the lines of force | Oscillations vertical to the lines of force | Mean error | Intensity | Δλ | $-\Delta\lambda\,\lambda^2$ | |
|---|---|---|---|---|---|---|---|
| | | 5.265 | | 3 | +265 | −1.98 | |
| | | 5.208 | | 4 | +203 | −1.56 | |
| | 5.181 | | | 2 | +181 | −1.35 | |
| | | 5.159 | | 4 | +159 | −1.19 | |
| | 5.108 | | | 5 | +108 | −0.81 | Possibly the same wave-length. |
| | | 5.102 | | 3 | +102 | −0.76 | |
| | 5.049 | | | 3 | + 49 | − 0.37 | |
| 3655.00 satellite | | | 0.0019 | | | | |
| | 4.949 | | | 3 | − 51 | +0.38 | |
| | | 4.897 | | 3 | −103 | +0.77 | Possibly the same wave-length. |
| | 4.891 | | | 5 | −109 | +0.82 | |
| | | 4.846 | | 4 | −154 | +1.15 | |
| | 4.822 | | | 2 | −178 | +1.33 | |
| | | 4.789 | | 4 | −211 | +1.58 | |
| | | 4.734 | | 3 | −266 | +1.99 | |
| | | 0.480 | 0.0056 | 5 | +170 | −1.28 | On some of the plates the components oscillating parallel to the lines of force are not separated. It may be that the separation consists only in an absorption of the middle line. All four components are much thicker than those of the other lines. |
| | 0.353 | | 0.0071 | 5 | + 43 | −0.32 | |
| 3650.31 principal line | 0.262 | | 0.0071 | 5 | − 48 | +0.36 | |
| | | 0.141 | 0.0056 | 5 | −169 | +1.27 | |
| 3027.66 satellite | 7.563 | 7.563 | 0.007 | 1 | + 97 | −1.06 | |
| | 7.757 | 7.757 | | 1 | − 97 | +1.06 | |
| 3025.79 satellite | ..... | ..... | ..... | .. | ..... | ..... | Not measured because the components were too weak. |

C. RUNGE and F. PASCHEN.

[1] See ASTROPHYSICAL JOURNAL, 15, 243, May 1902.

## WAVE-LENGTHS OF CERTAIN OXYGEN LINES.

In determining the radial velocities of certain stars having spectra of the *Orion* type we have found that some of the best measurable stellar lines are those due to oxygen. The presence of oxygen lines in the spectra of *β Crucis* and several other southern stars has been demonstrated by McClean[1] and by Gill.[2] The wave-lengths of the oxygen lines in the spark spectrum of air, by Neovius, and by Trowbridge and Hutchins, are given only to the tenth of the tenth-meter, as the hazy character of the lines rendered their precise measurement very difficult on the scale presumably employed. As an uncertainty of 0.1 tenth-meter in the wave-length of the stellar line corresponds to about 6.6 km in the velocity deduced from that line, more accurate values of the wave-lengths of these lines were essential before we could use the corresponding stellar lines. The arrangement of the apparatus for the study of the spectrum of the spark under water and under various other conditions in the spectroscopic laboratory of the Observatory, made it an easy matter to procure plates with the concave grating showing the spark spectrum of different metals with their arc spectrum in juxtaposition. Messrs. Ellerman and Kent were kind enough to take for us such plates of the spectra of iron, titanium, nickel and cobalt. One of the advantages of the use of different elements is the avoidance of the disturbance of the measurements of the air lines by nearby metallic spark lines. Thus the air line at λ 4415.08 cannot be well measured on an *Fe* plate because of the nearness of the strong *Fe* line at λ 4415.293; and the case is similar for the oxygen (air) line at λ 4417.12 with the *Ti* spark. The 6.5 meter concave grating gives a scale of about 2.6 tenth-meters per millimeter on the negative, and we were surprised to find how accordantly the settings could be made on the air lines despite their breadth. The measures were made with three different measuring machines by the two observers, working entirely independently and using different comparison lines in many instances. Measures were generally made with both violet to left and violet to right, but they are treated below as separate determinations, no systematic differences being clearly evident between the measures in the two positions.

We did not attempt to measure all the air lines in the range of spectrum we included, but took only those lines which have consider-

[1] *Proc. R. S.*, **62**, 418, 1898; "Spectra of Southern Stars," London, 1898.

[2] *Proc. R. S.*, **55**, 196, 1899; ASTROPHYSICAL JOURNAL, **10**, 272, 1899.

able strength in our stellar spectra and can be used in determining radial velocities.

In the following list the results of the two observers are given separately, with the number of measures made, generally on several different plates. The mean values are weighted according to the number of observations.

WAVE-LENGTHS OF CERTAIN OXYGEN LINES
(SPARK SPECTRUM OF AIR).

| Frost | | Adams | | Weighted mean |
|---|---|---|---|---|
| λ | No. | λ | No. | λ |
| 4317.27 | 3 | Not measured | .. | 4317.27 |
| 4319.76 | 3 | " " | .. | 4319.76 |
| 4345.67 | 4 | 4345.68 | 8 | 4345.68 |
| 4347.62 | 4 | Not measured | .. | 4347.62 |
| 4348.12 | 4 | 4348.14 | 5 | 4348.13 |
| 4349.53 | 5 | 4349.55 | 8 | 4349.54 |
| 4351.51 | 3 | 4351.49 | 6 | 4351.50 |
| 4366.99 | 6 | 4367.03 | 8 | 4367.01 |
| 4415.08 | 6 | 4415.07 | 6 | 4415.08 |
| 4417.11 | 6 | 4417.13 | 6 | 4417.12 |
| 4447.16 | 6 | 4447.17 | 8 | 4447.16 |
| 4591.08 | 6 | 4591.06 | 6 | 4591.07 |
| 4596.30 | 6 | 4596.28 | 6 | 4596.29 |
| 4601.63 | 7 | 4601.63 | 8 | 4601.63 |
| 4607.32 | 5 | 4607.30 | 8 | 4607.31 |
| 4614.03 | 4 | 4614.04 | 6 | 4614.03 |
| 4621.56 | 4 | 4621.54 | 8 | 4621.55 |
| 4630.71 | 4 | 4630.70 | 8 | 4630.70 |
| 4638.95 | 4 | 4638.93 | 4 | 4638.94 |
| 4641.90 | 4 | 4641.87 | 4 | 4641.89 |
| 4643.25 | 4 | 4643.24 | 4 | 4643.24 |
| 4649.26 | 4 | 4649.24 | 4 | 4649.25 |
| Not measured | .. | 4650.93 | 4 | 4650.93 |
| 4661.72 | 2 | 4661.73 | 4 | 4661.73 |

An estimate of the accuracy of these wave-lengths is somewhat difficult, and it did not seem worth while to separately determine the probable errors. For the line at λ 4367, for which the fourteen separate determinations are not in as good accordance as for the average air line, the mean error is ± 0.026; for the average line it would probably not exceed ± 0.02 tenth-meters.

EDWIN B. FROST and WALTER S. ADAMS.

YERKES OBSERVATORY,
August 25, 1902.

## THE MIRROR OF THE CROSSLEY REFLECTOR—A CORRECTION.

PROFESSOR KEELER'S most useful article describing the Crossley Reflector of the Lick Observatory, in the ASTROPHYSICAL JOURNAL of June 1900, contains the following paragraph :

> The large mirror, the most important part of the telescope, has an aperture of 3 feet, and a focal length of 17 feet 6.1 inches. It was made by Mr. Calver. Its figure is excellent. On cutting off the cone of rays from a star with a knife-edge at focus, according to the method of Foucault, the illumination of the mirror is very uniform. While the star disks, as seen in an ordinary eyepiece, are small and almost perfectly round, they are not, I think, quite so good as the images seen with a large refractor; still, they are very good indeed, as the following observations of double stars made recently for this purpose will show.

A correspondence with Sir Howard Grubb and Mr. J. Gledhill has proven to me that the figuring of this excellent mirror is the work of Sir Howard Grubb. Mr. Crossley's gift to the Lick Observatory included two mirrors essentially of the same diameter and focal length. These were distinguished by the letters A and B. An extract from Mr. Gledhill's letter is as follows :

> When we found that the A mirror was not good, and that the figure of the B was a little worse, we asked Dr. Common and Mr. Wassell (an expert in mirror testing by the Foucault method) to come and test them. They did so. Sir Howard Grubb was then called in, and he examined both mirrors. All the results of the tests agreed with ours. It was then decided to send the B mirror to be re-figured by Sir Howard Grubb; this was done, and you have it as it came from his workshop.

It is the B mirror which has been used in all the work with the Crossley Reflector at the Lick Observatory.

In justice to Sir Howard Grubb I herewith make the correction which of course the late Professor Keeler would very gladly have made.

W. W. CAMPBELL.

MT. HAMILTON, CALIFORNIA,
August 21, 1902.

## NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed.

Authors are particularly requested to uniformly employ the metric units of length and mass; the English equivalents may be added if desired.

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